

ENERGY EFFICIENCY IN CANADA'S PULP & PAPER INDUSTRY

Ellen F. Battle



**CANADIAN
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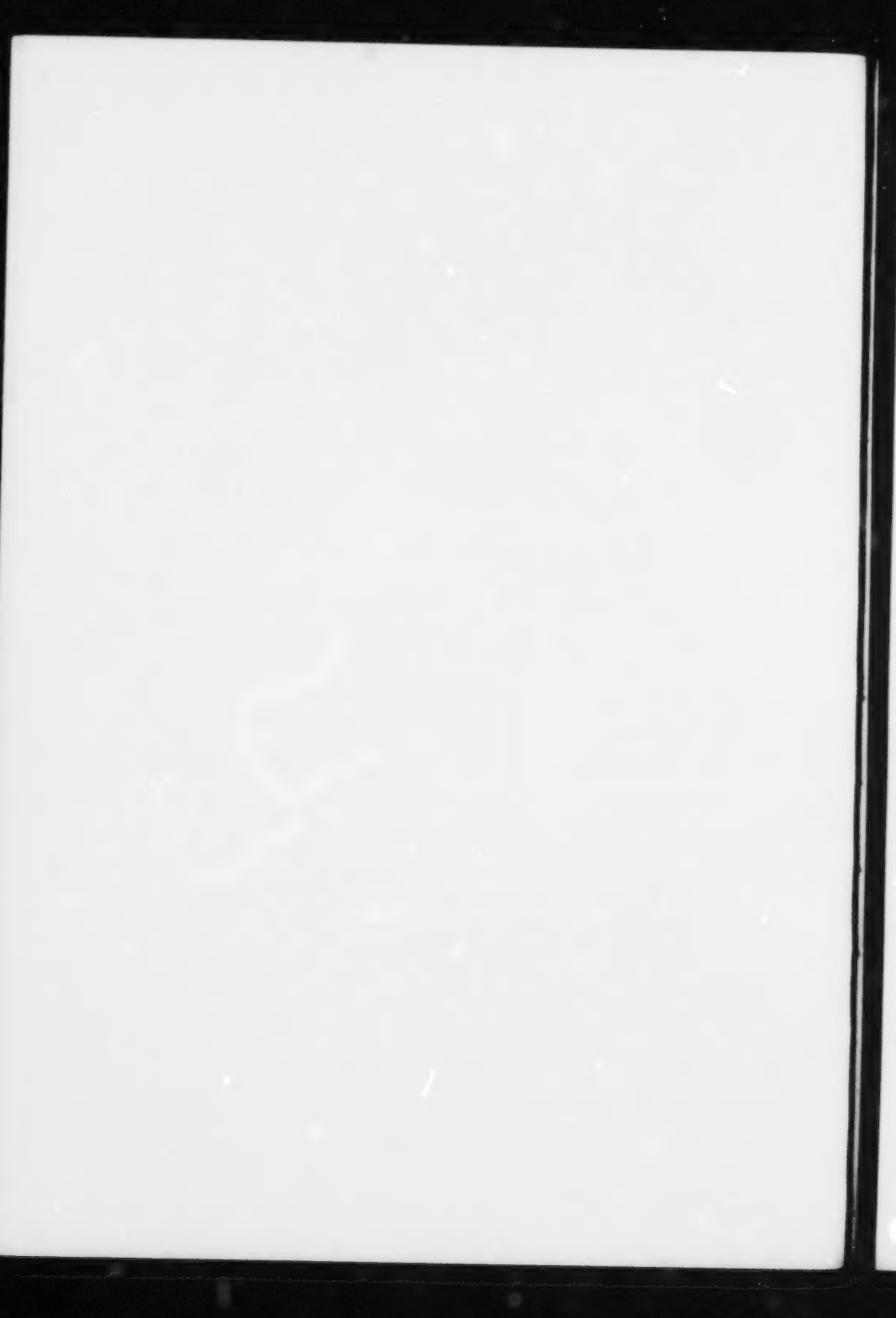
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PREFACE

This study was started in 1985 and completed in July 1986. Most of the data gathering took place between August and October of 1985.

The Institute would like to express its gratitude for the insights and helpful comments provided by the two-member Advisory Committee for this study. Special thanks go to H. D. Paavila at the Canadian Pulp and Paper Association in Montreal who supplied the energy database, and provided useful advice and comments throughout the course of the study. Thanks are also due to a number of individuals who assisted at various stages of the project including Andre Valade of EMR's Market Analysis and Statistics Division, and H. I. Simonsen and Keith Thompson of the Pulp and Paper Research Institute of Canada (PAPRICAN). However, the views and conclusions expressed herein are those of the author, who accepts sole responsibility for any errors or omissions that may exist.

The author is particularly grateful to Adele Crowley who was responsible for computer programming applications. Graphics work was performed by Anita Duclos, and Lise Taylor assisted in editing. Able typing assistance was provided by Donna Zimmerman and Janice Morrison.



EXECUTIVE SUMMARY

In the wake of rising energy prices, a number of studies have examined the trends in industrial energy demand over the past decade. These trends in energy use reflect a variety of complex factors, including shifts in the composition of output between more energy-intensive and less energy-intensive industries, business cycles, changes in product mix and production processes within specific industries, fuel substitution, availability and use of self-generated fuels, and energy conservation measures and technologies.

The purpose of this study is to investigate further the issue of changing energy use by focusing on one relatively energy-intensive industry: Canadian pulp and paper production. Using a mill-specific database of energy inputs, the trends in energy intensity are analyzed for the period 1976 through 1984. Furthermore, the analysis is conducted at a sub-industry level. In the case of pulp and paper, the appropriate level of aggregation is by major product type, in order to account for the energy-using characteristics of different production processes.

There are various ways to define energy intensity, including the quantity of total energy per RDP (Real Domestic Product) and the share of energy expenditures in total production costs. The definition adopted for this study is gigajoules of input energy per tonne of physical output. Input energy units signify that the energy quantities of component fuels have not been adjusted for utilization efficiency. According to this definition of intensity, an improvement in energy efficiency is given by a declining trend in total input energy per tonne of product.

The specific calculation of energy intensity involves dividing an index of aggregate energy consumption by an index of physical production. Two types of energy index are specified: (1) a "Btu index" which aggregates all fuel types on the basis of their heat or energy contents; and (2) a "Divisia quantity index" which weights the contribution of each fuel type by its share of total energy expenditures. The Divisia index has certain conceptual advantages; however, its use

in this study is limited by a lack of mill-specific price (cost) data for purchased and self-generated fuels.

Energy use is analyzed for the two largest product groups in pulp and paper manufacture: bleached kraft market pulp, and newsprint with integral sulphite pulp. These two product groups are characterized by substantially different patterns of energy demand. For example, almost 70 percent of the input energy requirements for kraft pulp are made up by process and wood wastes, and only 3 percent are accounted for by purchased electricity. In newsprint production, on the other hand, purchased power represents over 40 percent of total energy input, and less than 20 percent is recovered in the form of combustible wastes.

Table I presents selected study results for the Btu index of energy intensity. The data show a decline in both purchased energy per unit of output and total energy per unit of output, where total energy includes self-generated fuel and electricity.

TABLE I
INDEXES OF ENERGY INTENSITY
(1972 = 100.0)

Year	Kraft Pulp		Newsprint	
	Purchased Fuels	All Fuels	Purchased Fuels	All Fuels
1976	91.4	98.6	98.8	98.1
1977	84.9	100.8	93.8	95.6
1978	82.0	101.3	92.5	96.0
1979	84.6	99.1	87.3	93.0
1980	80.7	95.4	85.8	91.4
1981	81.2	96.7	83.9	90.2
1982	78.2	97.9	87.2	93.5
1983	65.5	92.2	83.3	92.9
1984	66.9	93.1	81.0	92.4

The difference between the Purchased Fuels and All Fuels indexes indicates the switching that has taken place out of higher cost purchased fuels (residual fuel oil (RFO) and, to a lesser extent, natural gas) and into lower cost waste by-products. This is particularly evident in the case of kraft pulp production which witnessed a

virtual halving of RFO use between 1976 and 1984. In the case of newsprint, there were declines in both natural gas and fuel oil consumption, accompanied by increases in wood waste and electricity use.

To summarize, the results of Table I reflect two components of changing energy demand in the Canadian pulp and paper industry: (1) the displacement of more expensive, purchased energy by less expensive, self-generated energy sources (fuel substitution); and (2) a decline in total energy use per output (energy conservation).

In terms of sensitivity analysis, the Btu indexes of energy intensity are adjusted to account for the combustion efficiencies of different fuels. The effect of adjusting for efficiency is to lower the All Fuels Index, as lower efficiency wastes are substituted for higher efficiency purchased fuels over the historical period.

Based on the investigation of energy-use patterns in pulp and paper, a number of general observations can be made with respect to analyzing industrial energy demand:

- Trends in energy intensity depend, in part, on the level of aggregation at which energy use is analyzed. Because of the heterogeneity of the industrial sector, this study concentrates on a single industry. However, the results for pulp and paper production also suggest a significant variation in consumption patterns from one product type to another and, for a given product type, from one mill to another. Even at the industry level, aggregate analysis conceals the impact of changing processes and product mix on the profile of energy demand.
- The results for the change in demand also depend on how energy intensity and efficiency are defined. For example, if energy use is specified in terms of total input energy in joules, then a switch from higher efficiency fuels such as RFO to lower efficiency fuels like wood wastes may result in an increasing trend in intensity through time. However, what matters to the industry producer is not the quantity of energy input but the cost savings that are available through off-oil substitution. Therefore, from an industry perspective, the more appropriate indicator for changing energy efficiency is energy's share of total production costs.
- The producer's objective is to minimize the cost of all production inputs labour, equipment, energy, and non-energy materials. According to this principle of

total cost minimization, it may be economic to increase energy consumption in order to economize on other high cost inputs such as raw materials or labour. Ideally, an analysis of energy use in a particular industry or firm should examine the relationship between energy and other inputs into the production process.

- The demand for energy is also a function of the emergence and decline of specific end uses. In the Canadian pulp and paper industry, for example, the trend towards greater electricity intensity reflects growth in two distinct uses for electric power: (1) boiler electricity demand, as a result of Hydro-Quebec's industrial discount program; and (2) motive electricity demand, due to various factors such as pollution control requirements, the growth in thermal mechanical pulping, and the substitution of mechanical for steam-drying methods in paper manufacture.
- In general, the results for changing energy use are influenced significantly by the way in which the analysis is defined: the specification of energy inputs, the definition of production, the choice of conversion efficiencies, the level of industry aggregation, and so on.
- Typically, trends in energy consumption for a given industry are the outcome of various offsetting factors including the level of capacity utilization, general technological progress, investment in energy-saving equipment, process changes, and the costs of labour and materials. To the extent that data could be assembled, it would be useful to assess, either at the industry or plant level, the contribution of each of these factors to the change in energy demand.

Chapter 1

INTRODUCTION

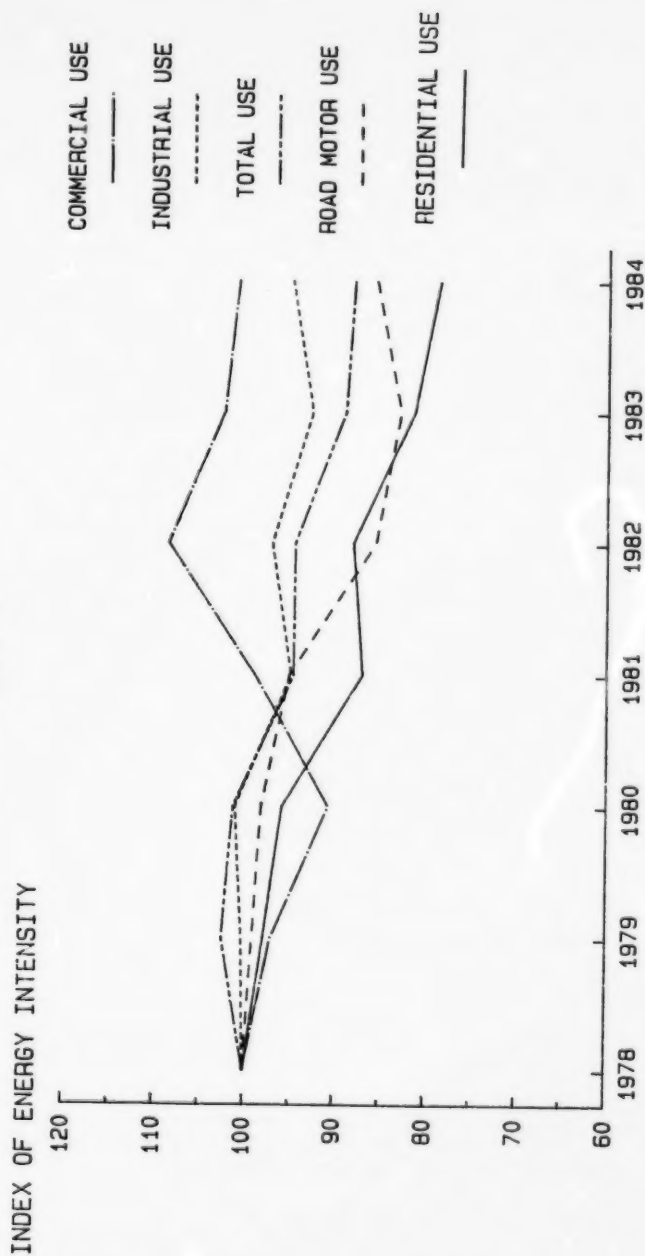
One of the key energy-related issues in recent years has been the effect of the rapid escalation in world oil prices during the past decade on industrial energy demand in Canada. There is evidence to suggest that since the late 1970s the country's largest energy user, the industrial sector, has witnessed a smaller-than-average decline in energy intensity (energy consumption per unit of economic activity) relative to other sectors of the economy (see Figure 1.1).¹ Here and elsewhere in the world, efforts have been made to explain, both through aggregate analysis and through examination of the trends in specific industries, the changes which have occurred in industrial energy demand.² The objective of these studies has been to determine whether the industrial sector in Canada has indeed become more "efficient" in its use of energy, and to assess whether further efficiency gains can be expected in the future.

Trends in energy intensity are composed of a number of complex factors: for example, shifts in the composition of output between more energy-intensive and less energy-intensive industries, business cycles and other behavioural changes in the economy, and changes in energy intensity within particular industries. Even for a given industry, the total change in energy intensity reflects shifts in the product mix, changes in production processes, technological development, and other influences.

The purpose of this study is to investigate further the pattern of total industrial energy use by focusing on one energy-intensive industry: Canadian pulp and paper production. The specific study objectives are:

- to discuss briefly some of the issues related to changing patterns of energy use in the industrial sector as a whole;
- to undertake a detailed historical analysis of the trend in energy intensity for Canadian pulp and paper production, using a plant-specific database; and

FIGURE 1.1
INTENSITY OF ENERGY USE
CANADA



Sources: StatsCan 57-003, 61-213, 53-219, and 13-567

- to compare the results of this historical analysis with other analyses of energy use in the pulp and paper industry.

There are a number of reasons for trying to explain trends in industrial energy consumption. Among the important questions for Canadians are:

- (1) How have energy intensities in the Canadian industrial sector changed relative to those in other countries? In particular, how has energy consumption in Canada been influenced by domestic energy pricing policies, compared to consumption in countries which have made a more rapid adjustment to rising energy prices? In addition to relative energy prices, other factors account for the variation in energy use from one country to another; for example, lags in the penetration of energy-saving technology, the prices of other inputs into the production process (labour, non-energy materials, and equipment), the availability of capital to a specific corporation or sector, climate, geography, and population density.
- (2) Has the change in industrial energy demand been consistent with Canadian policy goals of ensuring self-sufficiency in energy supply and more efficient use of resources? The federal government has sought to encourage energy conservation and the substitution of other energy forms for imported oil in all sectors. One aspect of these efforts has been the promotion of "alternative energy sources" for industry, such as renewables and combustible waste by-products.
- (3) What are the implications of changing energy use for Canada's competitive position in world markets? Much of Canadian industry is dependent on export markets. For those industries in which energy makes up a significant share of the total cost of production, the ability to reduce energy expenditures--i.e., by substituting lower cost fuels, purchasing energy-saving equipment, etc.--is an important element in maintaining or penetrating foreign markets. This ability to remain competitive, in turn, has implications for domestic employment, the balance of payments, etc.

In the remainder of this chapter, we review the results of some other analyses of industrial energy trends and provide a brief description of the Canadian pulp and paper industry. Chapter 2 contains a

general discussion of issues, as well as an outline of the study methodology for analyzing energy intensity. In Chapter 3, the mill-specific database is described. The results of the data analysis are then presented in Chapter 4. Finally, Chapter 5 compares these results with the findings of the analyses discussed in Chapter 1, and provides suggestions for further work.

1.1 Other Studies of Industrial Energy Demand

A number of Canadian and international studies have investigated the issue of changing energy demand in the industrial sector. In this section, we compare the results of two analyses: ongoing research by the Canadian Industry Program for Energy Conservation;³ and a 1984 report from the Market Analysis and Statistics Division of Energy, Mines and Resources Canada.⁴

1.1.1 The Canadian Industry Program for Energy Conservation (CIPEC)

In 1975, at the suggestion of the federal government, the Canadian Industry Program for Energy Conservation was established. CIPEC is a voluntary association of manufacturing companies which currently account for almost 85 percent of (purchased) industrial energy consumption excluding feedstocks. It is organized into 16 participating industry task forces whose purpose is several-fold: to increase awareness of energy conservation in industry; to set voluntary energy efficiency targets; to collect data and report on energy use; to maintain dialogue with government; and to facilitate the exchange of information.

In their annual reports, the individual task forces present data on purchased energy consumption disaggregated by fuel type.⁵ For each industry group, an estimate is made of the improvement in "net energy efficiency" between the current year and a base year period (usually 1972). First, the base year energy consumption is adjusted for current levels of physical output to give the "base year equivalent energy inputs." In some cases, an allowance is also made for differences in other factors--weather, degree of processing, quality of raw material inputs, non-productive use of energy for environmental control, etc.⁶ Then, the "net energy savings" are calculated by subtracting the current year level of energy use from the adjusted base

year energy consumption. Finally, the percentage change in net energy savings or efficiency is compared to a target value which is differentiated by industry and is subject to periodic revision.

According to the CIPEC analysis, Canadian industry has realized significant gains in energy efficiency over the last decade. For manufacturing as a whole, the average 1980 goal of a 15 percent reduction in energy use was achieved in 1979, while the 1985 goal of a 23 percent reduction was virtually met in 1984. The estimated efficiency gains and targets (percentage change) for selected energy-intensive industry groups were as follows:⁷

Industry Group	1984	1984/85
	Improvement	Goal
Chemicals	28.8	31.0
Ferrous Metals	7.2	7.1
Mining and Metallurgy	14.2	15.0
Petroleum Refining	24.1	25.0
Pulp and Paper	27.3	30.0
Total CIPEC (weighted average)	22.9	23.0

(It should be noted that for any given year the efficiency goals are not comparable across industries because they reflect different base year periods, starting levels of efficiency, conservation potential, etc.)

Typically, the inability of certain industries to meet or surpass the efficiency targets which they had set four years earlier was attributed to the economic recession of 1981/82. During this period, the progress towards energy-use goals was affected by low capacity utilization rates and thin profit margins. In terms of active conservation, the participating companies identified housekeeping and other lower cost, short payback projects as the most prevalent measures for reducing their total energy consumption. As for investment in energy-saving equipment and plant modernization, greater improvements were made in the early part of the program (1978 to 1980) when profits were generally more available to fund capital spending.

Table 1.1 shows the CIPEC results for the distribution of industrial energy use by fuel type. The figures for purchased energy indicate a significant shift away from liquid petroleum products, i.e.,

TABLE 1.1

FUEL SHARES IN INDUSTRIAL ENERGY DEMAND -
CANADIAN INDUSTRY PROGRAM FOR ENERGY CONSUMPTION
(percent)

	Electric Power	Natural Gas	LPP ^a	Coal & Coke	Other Fuels ^b
<u>Selected Industries 1984</u>					
Chemical	14.8	59.0	6.0	0.5	19.7
Ferrous Metals	7.1	18.3	5.0	69.6	-
Mining and Metallurgy	43.6	21.2	26.2	7.4	1.6
Petroleum Refining	4.8	20.2	11.5	18.2	45.3
Pulp and Paper	42.3	26.2	28.6	3.0	(0.1)
Total CIPEC 1984	19.1	32.3	16.7	19.2	12.7
1983	19.1	32.3	17.1	19.2	11.9
1982	18.7	29.5	22.1	18.0	11.7
1981	17.1	29.0	22.2	17.8	13.9
1976 ^c	22.3	35.8	28.5	12.8	0.6

SOURCE: CIPEC Annual Reports.

^aLiquid Petroleum Products.

^bIncludes propane, LPGs, by-products and waste, purchased steam, refinery gas and miscellaneous fuels, but excludes wood wastes.

^cBased on Statistics Canada sources.

heavy fuel oil and distillates. There have been increases in the shares of both coal/coke and other fuels, due in part to their substitution for fuel oil and to production increases in the industries in which they are used (i.e., iron and steel, and chemicals). The shares of natural gas and electricity have remained more stable, although recently these fuels have made some small gains at the expense of fuel oil. One reason for the rise in electricity's share has been an industrial incentive program in the province of Quebec to encourage conversions to electric steam-generation boilers.

1.1.2 The 1984 EMR Study

In their 1984 study entitled Industry Energy Demand: A Review of Recent Trends,⁸ Halliwell and Valade use Statistics Canada data to assess the changes that have taken place in industrial energy intensities. Energy intensity is defined as energy consumption in thermal units (gigajoules) per unit of constant dollar real domestic product. The information on energy use is derived from two Statistics Canada sources: (1) Quarterly Report on Energy Supply-Demand in Canada (QRES), Catalogue 57-003; and (2) Consumption of Purchased Fuels and Electricity (CPFE), Catalogue 57-208. There are inconsistencies between these two data sources with respect to both their definition of industries and their reporting of fuels. Some of the differences, as noted by the authors, are described below.

The QRES data report final energy demand⁹ by major industry grouping in the construction, manufacturing, mining, and forestry sectors from 1978 onwards. The data for the industrial sector exclude petrochemical feedstocks, as well as refined petroleum products within the petroleum refining industry (treated as producer consumption). In addition, the division of fuels between forestry and the pulp and paper industry allocates all diesel fuel oil to the former and all heavy fuel oil to the latter.

The CPFE data on energy use are available for a longer time period (extending back to 1962) than the QRES, but relate only to purchased fuels. Excluded are feedstocks and non-purchased fuels such as wood wastes in the pulp and paper industry, own-generation of hydro-electricity within the smelting and refining industry, and coking coal and coke oven gas consumed in the iron and steel industry (treated as raw material inputs). The data include the total quantity of fuels

purchased to generate electric power, unlike the QRESO data which report only the final consumption of electricity.

Table 1.2 presents selected results of the calculation of energy demand per unit of RDP using the QRESO and CPFE databases. Between 1978 and 1983, total industrial intensity of energy use fell by some 4 percent; however, the results for specific industries were mixed. In pulp and paper production, for example, there was a clear decline in the intensity of purchased energy but an upward trend in energy demand including the consumption of renewables, reflecting the strong growth in wood and process wastes.

In iron and steel, the QRESO data indicate a slight downward trend in energy intensity while the CPFE data, which omit coking coal, show an increase in unit energy demand.

According to the Statistics Canada data, the most energy-intensive industries have not demonstrated a decisive decline in energy intensity over the historical period. Indeed, the greatest reductions in demand appear to have come from the least energy-intensive sectors, such as construction and other manufacturing. The authors of the EMR study suggest that other factors, such as declining resource quality, capacity utilization, etc., may be complicating the trends in energy efficiency for resource-based industries like pulp and paper, iron and steel, and aluminum production.

In terms of the distribution of energy use by fuel type, the EMR analysis found a decline in the share of fuel oil across all industries. The shift away from oil has been absorbed primarily by other fuels including coal, coke and renewables. On average, the share of natural gas has declined, whereas electricity's share has increased in all sectors.

The EMR study also considers the impact of business cycles, capacity utilization rates, and the vintage of the capital stock on trends in industrial energy demand. These issues are mentioned in later chapters. For now, we provide a brief comparison of the CIPEC and Halliwell and Valade results.

TABLE 1.2

ENERGY INTENSITIES IN THE INDUSTRIAL SECTOR -
EMR STUDY RESULTS
(GJ/\$1971 K)

	Total Industrial	Pulp and Paper	Iron and Steel	Smelting and Refining	Chemicals	Cement	Other Manufacturing
<u>QIESD</u>							
1978	61.4	444.2	311.5	318.1	116.5	404.5	25.6
1979	61.4	454.0	303.5	334.4	132.0	454.9	24.1
1980	62.7	460.6	329.4	314.9	134.4	500.3	24.9
1981	58.8	454.0	316.3	298.1	127.0	459.0	22.0
1982	61.5	501.6	315.1	318.1	135.8	460.2	23.4
1983	58.9	471.4	305.8	314.8	101.7	453.3	21.1
1983/1978	-4.1%	+6.1%	-1.8%	-1.0%	-12.7%	+12.1%	-17.6%
<u>CPFE</u>							
1974	↑	268.6	100.3	207.3	128.0	489.2	22.6
1975		302.0	107.9	207.3	127.0	494.7	22.7
1976		291.6	101.9	218.9	125.3	479.6	22.0
1977	N.A. ^a	276.6	112.7	170.6	114.2	453.8	21.6
1978		247.7	119.5	179.6	122.6	464.5	21.6
1979	↑	252.8	114.3	193.2	110.9	469.5	21.0
1980		240.3	120.5	179.6	120.0	447.6	21.1
1981		237.6	118.0	176.6	126.5	418.7	21.0
1981/1974		-11.5%	+17.6%	14.8%	-1.2%	-14.4%	-7.1%

SOURCE: Halliwell and Valade (1984).

^aNot Available.

1.1.3 Comparison of the CIPEC and EMR Analyses

There are some similarities in approach and results between the 1984 EMR study and the monitoring of energy use by the Canadian Industry Program for Energy Conservation. A comparison of the methodology, data, and results of the two analyses is provided below.

1.1.3.1 Methodology

Both the CIPEC and EMR analyses of energy use are based on the measurement of input energy requirements, as opposed to output energy or the energy available to perform work (i.e., adjusted for end-use efficiency). The use of input energy is convenient because it is readily observable, e.g., it can be taken from company billing records. However, an efficiency-adjusted measure is preferable because it allows output to be tied directly to the energy actually used for the production process.

In addition, the CIPEC and CPFE databases do not account for transformations from one energy type to another within the plant--coal to coke in iron and steel production, the cogeneration of electricity from fossil fuels and wastes in the pulp and paper industry, etc. The QRES data on energy use do take account of these conversions, reporting only final energy demand.

Another common feature between the CIPEC and EMR approaches is the aggregation of different fuels into total energy use on the basis of the thermal content of the fuels. As will be discussed in the next chapter, there are conceptual difficulties involved in adding up energy types using heat content alone.

The CIPEC measure of energy intensity is defined as the quantity of purchased energy inputs, in joules, divided by the quantity of physical output, in tonnes. Given this formulation, any activity which reduces the amount of purchased energy without affecting the level of physical output (e.g., the substitution of self-generated energy for high cost purchased fuels) will result in an improvement in efficiency.

The EMR study measures energy intensity by examining energy input per unit of RDP. With RDP in the denominator, there may be

inherent biases in the intensity expression. For example, using the CPFE data for purchased fuels only, a reduction in purchased energy will cause the numerator of the energy-intensity measure to fall. But, as Halliwell and Valade point out,¹⁰ it will also have an impact on RDP. Since RDP is calculated as a measure of value added--real output less the real value of energy and other material inputs--any reduction in energy will, *ceteris paribus*, increase the value of RDP. The overall effect should be to make the improvement in energy efficiency more pronounced, with the bias being greater the more energy-intensive the industry. However, even for an energy-intensive industry like pulp and paper, the size of the bias is not likely to be large given that energy still accounts for less than 20 percent of total costs (see Section 1.2).

As well, there are price effects which may bias the measure purchased energy per unit of RDP. For example, since value added is composed primarily of labour, a rise in wage rates can cause the energy intensity index to decline. Because of these types of biases, it is not clear that a fall in purchased fuels will necessarily lead to a declining trend in energy use per RDP. The same can be said when nonpurchased fuels are included in energy demand, as in the QRESO database. For example, if lower-efficiency combustible wastes are substituted for higher-efficiency purchased fuels, then input energy per unit of RDP may actually rise. This is due to the fact that a high proportion of the heat contained in the wastes is lost in the combustion (and conversion) processes; therefore, more wastes must be burned to obtain an amount of steam equivalent to that obtained from burning purchased fuels. Under such circumstances, it would be more appropriate to specify an efficiency-adjusted measure of energy demand, i.e., total output energy.

The use of physical units of output in the denominator of the energy-intensity measure (CIPEC) has certain advantages in that this output embodies the economic activity in the plant for which energy is required. A problem with physical production is that it does not capture changes in the quality of output over time. For example, in the pulp and paper industry the quality of newsprint is continually being improved with such developments as thermal mechanical pulping (TMP) which produces a stronger, more absorbent paper. In recognition of these kinds of changes, the CIPEC energy reporting allows adjustments to account for shifts in product mix, greater degree of processing, etc.

Whether RDP (Halliwell and Valade) is effective in capturing improvements in quality depends on the extent to which these improvements are reflected in product prices. The TMP process results in higher energy costs; however, it reduces the requirement for higher cost chemical pulp in newsprint manufacture. Such cost changes are embodied in RDP, but quality improvements may or may not be accurately represented in prices. In fact, the trend in pulp and paper appears to have favoured increasing quality with an attempt to keep prices reasonably level.

In general, industry RDP is more removed from the production process than is physical output; that is, it includes the value added of administrative services, sales operations, taxes, and other cost items. Furthermore, it has been criticized by industry representatives for not tracking, in an accurate and timely manner, changes in industrial output and prices. In view of these problems, and the other biases noted above, it might be more appropriate to link energy demand to the cost of all production inputs—for example, to total manufacturing costs or the value of manufacturing shipments (see Section 1.2).

1.1.3.2 Data

Aside from these methodological differences, there are differences in the quality of the CIPEC, CPFE, and QRESO data. Generally speaking, the reporting of energy-use data has improved since the late 1970s. Surveying procedures have improved and a better effort is being made to collect information on alternative energy sources such as waste by-products. The problem with this improvement in quality is that data inconsistency may obscure the trends in energy use through time.

The CIPEC data on energy consumption and output have the advantage of coming directly from the user, often the company's energy department. The survey coverage varies across industries, with good coverage (85 percent or more of energy use in the industry) for pulp and paper, iron and steel, petroleum refining and wood products, and coverage of some 60 percent for manufacturing.

The Statistics Canada data provide a good coverage but there are some gaps and inconsistencies through time (reassignment of fuel categories, etc.) in both the CPFE and QRESO data. The CPFE data are based on surveys of company accounting departments and involve a certain amount of estimation of fuel quantities.¹¹ The QRESO data are compiled using surveys of major energy suppliers who are asked to

estimate the consumption of their various customers. Typically, however, the Statistics Canada data are fairly good for large energy users.

1.1.3.3 Results

Both the CIPEC and EMR results show the same basic trend for movements in fuel shares over the historical period--a substitution of other fuels such as coal and renewables for refined petroleum products. However, the results for changes in total energy intensity differ.

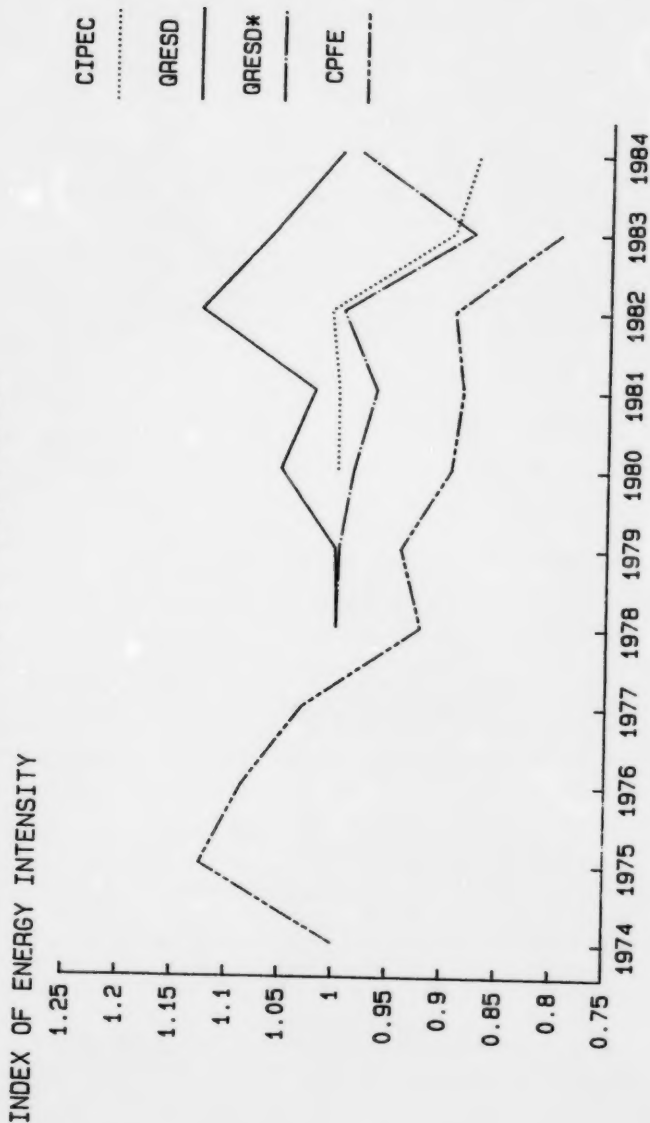
Figures 1.2 and 1.3 present a comparison of the CIPEC and EMR estimates for two industries: pulp and paper, and iron and steel. These industries have been selected because, in the annual CIPEC reporting, the relevant industry task forces present data on output from which to determine energy intensity.¹² The EMR analysis has been extended for more recently available data from the CPFE (1982 and 1983)¹³ and QRES (1984) databases.

For both industries, the CIPEC estimates of purchased energy show an unambiguous decline in intensity. The Statistics Canada purchased fuel data (CPFE) indicate a decline in unit-energy consumption for pulp and paper, but an increase for the iron and steel industry. As noted by the authors of the EMR study, these results for iron and steel are probably suspect due to the exclusion of coking coal and coke oven gas from the CPFE data.

All three indexes for iron and steel level off somewhat over the 1978-1982 period, and the QRES data suggest a downward movement. Halliwell and Valade cite the highly modernized nature of the Canadian steel industry as a possible explanation for the absence of any strong intensity changes.

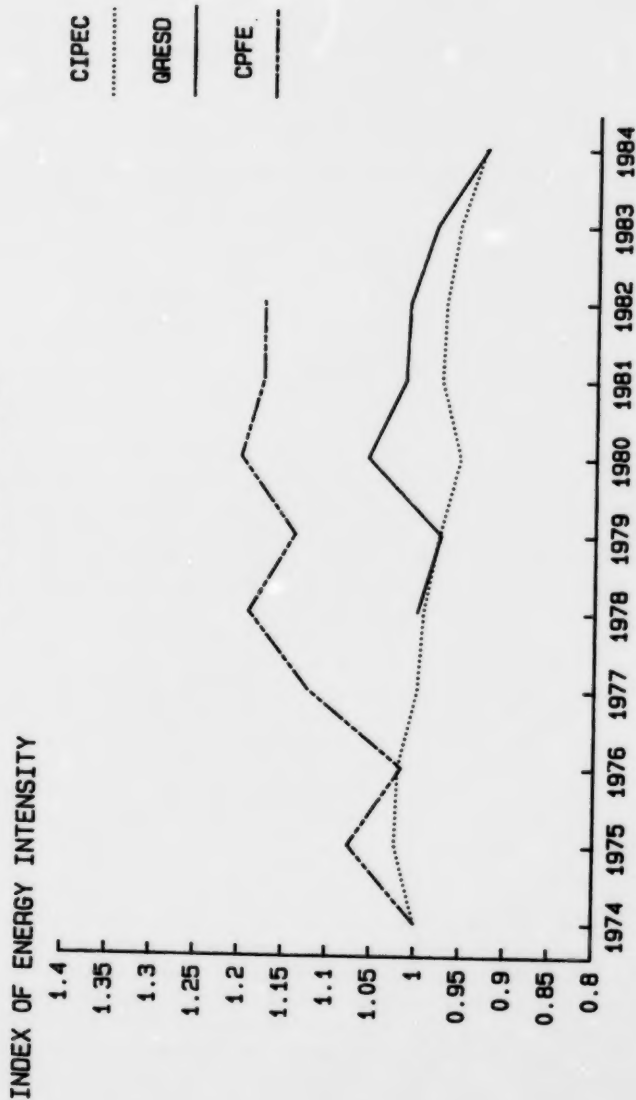
In pulp and paper, there is a trend towards increased energy use between 1978 and 1983 when renewables--wood and process wastes--are added into purchased fuels (QRES).¹⁴ The use of renewables grows by 25 percent over this period, and when this energy source is subtracted from the QRES data (as represented by QRES* in Figure 1.2), a general downward trend in intensity results. Hence, the rise in total energy intensity could reflect an efficiency effect of switching out of residual fuel oil and into wastes (see Section 1.1.3.1). After 1983, the trend is interrupted due to a 20 percent drop in the consumption of renewables.

FIGURE 1.2
TRENDS IN ENERGY INTENSITIES
PULP AND PAPER



QRESO* - QRESO minus waste by-products.
Sources: CIPEC Annual Reports, Halliwell and Valade (1984), and StatsCan 57-003 and 57-208.

FIGURE 1.3
TRENDS IN ENERGY INTENSITIES
IRON AND STEEL



Sources: CIPEC Annual Reports, Halliwell and Valade (1984), and StatsCan 57-003 and 57-208

The discrepancies between the CIPEC and EMR results highlight the importance of the choice of measurement tool in the analysis of energy intensity; for example, purchased versus total energy consumption, input energy versus efficiency-adjusted energy use, and energy per unit of physical output versus energy per unit of RDP. In this study, we compare several of these different measures for a sample of products in the pulp and paper industry.

1.2 The Canadian Pulp and Paper Industry

Pulp and paper production is one of Canada's major manufacturing industries, accounting for some 8 percent of manufacturing RDP and 12 percent of the value of manufacturing shipments.¹⁵ In 1984, the industry as a whole produced 22.2 million tonnes of pulp, newsprint, other paper and paperboard. Of this total, 9.9 million tonnes were shipped to other countries, constituting 9 percent of the value of total domestic exports.¹⁶

Pulp and paper has developed into a highly integrated, capital-intensive industry. It is also a major user of energy, accounting for 22.9 percent of the value of purchased industrial energy and 28.8 percent of the quantity of final energy demand including renewables.¹⁷ Table 1.3 presents some statistics on the energy intensity of pulp and paper production, in terms of purchased energy costs, relative to the total manufacturing sector.

The Canadian pulp and paper industry was built when energy costs were a small component of the total costs of production. Many companies, particularly in the eastern part of the country, located near rivers, developed their own hydroelectric generation capacity. As labour and material costs rose through the 1960s and early 1970s, producers were most concerned with looking for ways in which to economize on raw material inputs without incurring higher labour costs. Typically, the mechanized nature of pulp and paper production carried with it relatively high energy requirements.

Given the many pressures on the industry--escalating labour costs, stricter pollution standards, increased competition in world markets, an emphasis on plant modernization--energy expenditures were historically assigned a relatively low priority in cost control strategies. However, as the OPEC oil price shocks of 1973/1974 and 1979/1980 filtered through to industry and energy prices began to rise, more and

TABLE 1.3
RELATIVE ENERGY INTENSITY OF THE
CANADIAN PULP AND PAPER INDUSTRY, 1981^a

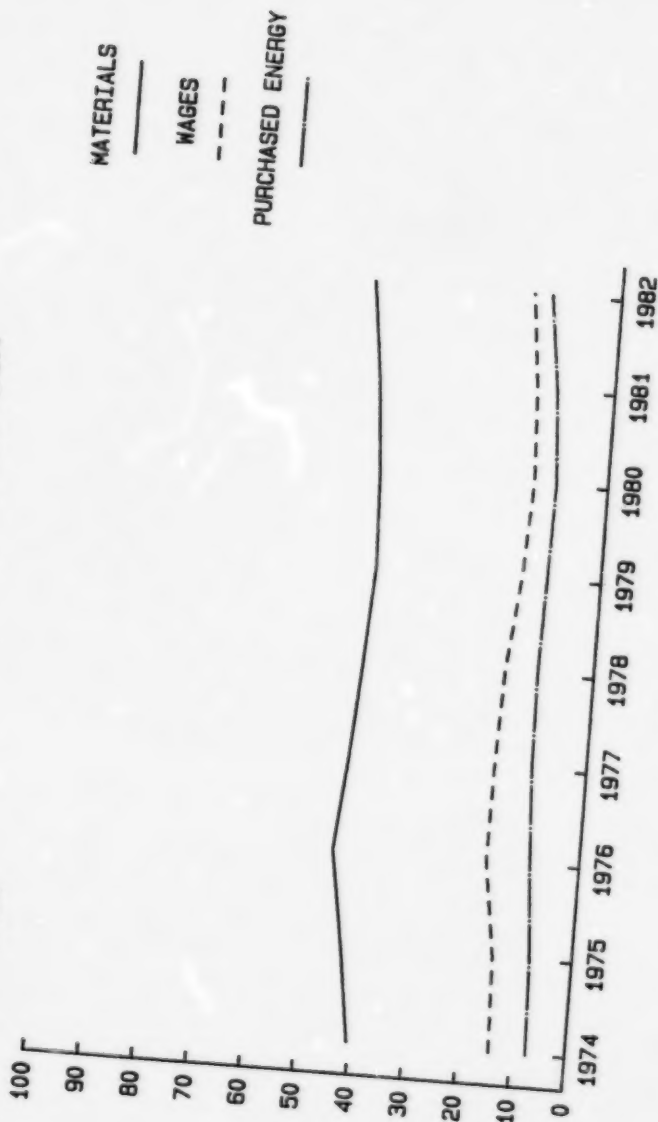
	Pulp and Paper	Total Manufacturing
Cost per Establishment (\$000)	8610	158
Cost per Employee (\$000)	18	4
Cost as % of Manufacturing Materials	24	5
Cost as % of Manufacturing Value-Added	23	8
Cost as % of Value of Manufacturing Shipments	11	3

SOURCE: Data from Statistics Canada 31-203 retrieved from CANSIM.

^aBased on current dollar cost of purchased fuel and electricity.

FIGURE 1.4
TRENDS IN COST SHARES
% OF VALUE OF MANUFACTURING PULP AND PAPER PRODUCTION
SHIPMENTS (CURRENT DOLLARS)

18



Source: StatsCan 31-203

more attention was given to energy conservation measures along with the displacement of fuel oil by wood and process wastes.

In spite of these conservation measures, the impact of rising energy prices has been felt in the pulp and paper industry. Figure 1.4 shows manufacturing materials, production wages, and purchased fuel and electricity as percentages of the value of manufacturing shipments. As indicated in the figure, materials account for the largest share of total production cost, and purchased energy for the smallest. Nevertheless, energy's share grew at an average annual rate of 5.8 percent between 1974 and 1981, while the shares of materials and wages grew at a corresponding 1.1 and 1.9 percent per year, respectively.¹⁸

Cost escalation is of critical importance in the pulp and paper industry, where competition for world markets is keen. Canada faces growing competition from the southern United States, Scandinavia, Asia, Brazil, and South Africa in the marketing of pulp, paper, and paperboard. In this context, although purchased energy makes up the smallest proportion of total operating expenditures, its costs may still be easier to control than those of other inputs such as materials and labour. On the other hand, overall cost minimization may dictate that energy use be increased in order to economize on more significant inputs like raw materials. Ideally, an analysis of energy use in a particular industry should examine this total cost minimization and the relationships between inputs (labour, materials, energy and equipment) in the production process.

Footnotes

¹In 1984, the sectoral breakdown of total Canadian energy demand excluding feedstocks (non-energy use) and producer consumption was as follows: residential and farm, 21.7 percent; government and commercial, 18.1 percent; transportation, 27.6 percent; and industrial, 32.6 percent. Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, Catalogue 57-003.

The indexes of energy intensity in Figure 1.1 are based on the following measures: energy demand per unit of real domestic product for commercial, industrial, and total use; energy demand per household for the residential sector; and energy demand per registered motor vehicle for road motor (gasoline and diesel) use. Residential energy use includes agriculture (with the exception of farm motor gasoline and diesel) and the commercial sector includes public administration. The industrial sector is defined as the sum of forestry, mining, manufacturing, and construction. Road motor use refers to retail pump sales of motor gasoline and diesel.

²For an example of aggregate-level analysis of energy demand, see Steve Rive, International Comparison of Energy Use (Ottawa: Macroeconomics Division, Energy, Mines and Resources Canada, October 1984).

³CIPEC Task Force Council, Canadian Industry Program for Energy Conservation (Ottawa: Energy, Mines and Resources Canada), various annual reports.

⁴Cliff Halliwell and Andre Valade, Industry Energy Demand: A Review of Recent Trends (Ottawa: Market Analysis and Statistics Division, Energy, Mines and Resources Canada, 1984).

⁵The individual task forces produce yearly reports which are submitted to the CIPEC Task Force Council. The Council then compiles these reports in a document covering all the participating industries. See footnote 3.

⁶The methodology for calculating this energy efficiency improvement is laid out in two CIPEC manuals: Energy Accounting Manual - Basic and Energy Accounting Manual - Advanced. The advanced manual details energy adjustment factors for plant disruptions (e.g., strikes), plant expansion, new equipment, new plants or products, raw material quality changes, weather, unavoidable changes in fuel type, utilization rates, and regulatory safety and environmental changes. Of the major energy-using industries (chemicals, iron and steel, mining, petroleum refining, and pulp and paper), petroleum refining made the most significant adjustment (27 percent in 1984) to base year energy consumption to account for product mix, environmental factors, degree of processing and utilization. See *supra*, footnote 3, 1984 Report.

⁷*Supra*, footnote 3, 1984 Report.

⁸*Supra*, footnote 4.

⁹"Final energy demand" refers to energy use after all transformations--i.e., fossil fuels to electricity, coal to coke, etc.--have taken place.

¹⁰Supra, footnote 4, pp. 6-7.

¹¹Basically, the accounting departments tend to have better information on fuel costs than on fuel quantities. Thus, for example, they may report volume of fuel purchased rather than volume of fuel consumed.

¹²Unlike pulp and paper and ferrous metals, several of the CIPEC industry groups do not have homogeneous outputs for aggregating into total production.

¹³The iron and steel analysis for CPFE has only been extended to 1982 because of restructuring of the SIC codes between 1982 and 1983.

¹⁴The rise in total energy use for 1982 is due to the impact of the recession on output.

¹⁵The RDP share is for paper and allied industries and is taken from Statistics Canada, Gross Domestic Product by Industry, Catalogue 61-213 (retrieved from CANSIM). The share of value of shipments is taken from Statistics Canada, Manufacturing Industries of Canada - National and Provincial Areas, Catalogue 31-203 (retrieved from CANSIM).

¹⁶Canadian Pulp and Paper Association, 1984 Reference Tables (Montreal: CPPA, December 1985), p. 5 and p. 7.

¹⁷Purchased energy is for pulp and paper mills (1983) and is taken from Statistics Canada, Consumption of Purchased Fuels and Electricity, Catalogue 57-208. Final energy demand is for pulp and paper and sawmills (1984) from Statistics Canada 57-003, supra, footnote 1.

¹⁸The year 1982 has been excluded because of the economic recession.



Chapter 2

METHODOLOGY

In this chapter, we begin by defining a number of relevant concepts: the demand for energy, energy intensity, and conservation. Then, some of the general issues related to trends in industrial energy use are discussed. In the final part of the chapter, we outline a methodology for estimating historical energy-intensity relationships and describe our approach for applying this methodology to the Canadian pulp and paper industry.

2.1 Concepts

There are many different definitions and connotations associated with the concepts of energy use and energy efficiency. Before proceeding with an analysis of the trends in industrial energy demand, it is useful to examine some of these definitions as they have evolved in recent years.

2.1.1 Energy Demand

Energy use in the industrial sector consists of several broad applications. The largest of these is the demand for energy as a source of process heat, that is, in the form of steam to be used in the production process. Other applications include space heating of production facilities and the use of electricity for lighting and electric motor drives. In addition, there are some industries which require specific energy types as an integral part of their production process; for example, the use of coal in the steel industry and electric power in the manufacture of aluminum.

The recent literature on energy demand emphasizes the notion of a desire for "energy services":

People often talk about the demand for energy. Yet if one thinks about it, there is no demand for energy. No one eats it, wears it, manipulates it, or in any other way directly uses it. It is strictly a means of providing some more readily identifiable service . . . The actual demand is for comfortable rooms, machines that run, or steel that can be formed—not for energy itself.¹

In the context of industrial energy, this desire for useful services is reflected in the notion that energy demand is essentially "derived" in nature. According to economic theory, inputs into the production process--labour, capital/equipment, energy, and non-energy materials--are combined in such a way as to meet most economically the demand for the final product(s).

With this specification of energy services, it is possible to conceive of different combinations of fuels and energy-using technologies which can serve a given end use. Demand may be satisfied through conventional fuels and technologies, or through alternative energy sources such as renewables, combustible wastes, and conservation technologies such as more efficient boilers and machines, improved plant insulation, etc. What matters to the end-user in his choice among different energy "packages" is the achievement of a desired quantity and quality of services.²

2.1.2 Energy Intensity

Energy intensity relates the demand for energy services to some reference point of economic activity, for example, the number of households, level of output, etc. In the industrial sector, energy intensity is frequently defined as consumption of energy in thermal units (Btu's or joules) per constant dollar of gross domestic product. Alternatively, intensity may be defined in a number of different ways: energy consumption per unit of physical output (e.g., tonnes of production), the ratio of total expenditures on energy to total production costs, or energy use per plant or per employee.

The purpose of these measures of unit energy demand is to determine the concentration of energy in specific industries and, for a given industry, to assess the importance of energy relative to other inputs into the production process. They also allow for a comparison of energy use across industries and for the tracking of conservation or improved energy efficiency over time.

2.1.3 Energy Conservation and Efficiency

According to the energy services concept, conservation means the use of a given energy unit to provide a greater level of services.³ To turn the argument around, it means performing a given

task with fewer energy units. Conservation can take the form of curtailed energy use (forced energy saving) or of increased energy productivity through changes in the equipment stock and daily consumption behaviour. In the industrial sector, this "productive conservation" includes such activities as the recovery of waste heat, investment in energy-saving equipment, reductions in product wastage, and better monitoring of energy use.

Conservation is reflected in a declining trend in energy intensity through time. If intensity is expressed in terms of thermal units of input energy, then conservation will entail any activity which reduces the use of one or more types of energy, or which substitutes a more efficient for a less efficient energy type. If intensity is specified on the basis of energy expenditure, then conservation will also include any activity which otherwise reduces the costs of production, for example, the displacement of high cost fuels by lower cost waste by-products. Thus, "energy efficiency" can be defined broadly to include all measures which minimize the cost of a given level of energy service.

From the perspective of industry managers, what matters most in the use of energy and other inputs is how the total cost of production is changing over time, and how that total cost can be minimized. Therefore, one way to analyze energy intensity trends is to track movements in the shares of energy, labour, materials, and other expenditures in total production cost ("factor cost analysis").⁴ In some cases, it may be economic to use more energy in order to reduce expenditures on other high cost inputs like labour and materials. Therefore, energy conservation should not be considered as an isolated goal; rather, it should be evaluated in the context of overall production efficiency.

2.2 Issues

Various factors influence the demand for industrial energy and, by extension, trends in unit-energy consumption over time. Some of the more important issues are described briefly below.

2.2.1 Energy Prices

Clearly, the price of energy and the relative prices of different fuels are key determinants of industrial energy demand. In

Canada, as in the rest of the world, the oil price shocks of 1973/1974 and 1979/1980 had a substantial impact on real energy prices. The effect of rising energy prices is both to reduce total energy consumption and to encourage the replacement of higher cost energy sources by lower cost energy sources.

Ultimately, the impact of higher industrial energy prices depends on a variety of factors including the relative importance of energy in total costs and the responsiveness of product demand to higher product prices. In the case of pulp and paper production, the impact of rising energy prices is comparatively strong because the industry is a major energy user and is subject to keen competition in world markets.

2.2.2 Other Production Inputs

The prices of other inputs--labour, equipment, and non-energy materials--also affect industrial energy demand, depending on how these different inputs interact in the production process. Similarly, energy prices have implications for the demand for labour, other materials, etc. For example, if energy prices are rising faster than those of other inputs, then there will be an incentive to undertake energy-saving measures, i.e., to buy more energy-efficient machines, install control systems to improve plant lighting and heating, upgrade insulation, etc. In economic jargon, this is referred to as "factor substitution" (labour, equipment, and other materials for energy) within the production process.

Typically, a distinction is made between the "short run," when inputs tend to be used in relatively fixed proportions to produce output, and the "long run," when the input mix tends to be more flexible. Hence, in the short run it may not be feasible to buy new energy-saving equipment, and the response to rising energy prices may be to incur the labour and other costs of "housekeeping" measures (turning down thermostats, tightening valves, etc.), improved operating procedures, and plant retrofits (e.g., insulation). Then, in the long run, the response may well be to purchase efficient machines and introduce new energy-saving processes.

2.2.3 Composition of Output

Trends in total energy use depend, in part, on movements in the composition of output between more energy-intensive and less

energy-intensive industries. On average, the more energy-intensive industries in Canada have realized a declining share of total RDP over the long term.⁵ Also, changes in the composition of output for individual industries (i.e., the product mix) have had an impact on aggregate energy demand. In general, the pattern of industrial energy use is a function of specific end-use applications--the appearance and decline of different products, the development of new processes, etc.

2.2.4 Capacity Utilization

Energy intensity can vary with the degree to which industrial capacity is utilized. Normally, energy use in a production facility is the sum of two components: fixed or "overhead" energy, and variable energy. Overhead energy is energy which is essentially invariant to the volume of product being produced and includes lighting, space heating, ventilation and any relevant process heating applications (e.g., maintaining ovens and furnaces which have to be kept warm). Variable energy moves in relationship to the volume of output, although not necessarily in a linear fashion. Most plants are less energy-efficient at low utilization rates, and efficiency improves as the level of production moves toward design capacity.

The impact on energy demand of an economic downturn is not clear cut. There will be an incentive to cut back on output and shut down production facilities where possible. If older, less energy efficient facilities are shut down first, then unit-energy use may actually decline. On the other hand, if there is a significant proportion of overhead energy in total energy demand or if the plant is not operating close to its design capacity, then energy intensity may increase. In some cases, there may be a "lumpiness" in energy use. For example, within certain ranges of plant utilization, it may not be feasible to shut down equipment, whereas if output drops substantially it may be economic to close an entire production line.

2.2.5 Technology

The ability of industry to reduce its unit-energy demand is constrained by existing technology. New technologies such as energy-saving machines and improved production processes may be fuel-specific, increasing or reducing the conservation potential of different energy types. Whether a firm can implement a new energy-efficient technology

depends on several factors such as the vintage of its equipment stock, R & D requirements, the menu of competing investments, and the cost of installing new equipment. Furthermore, there is a technological lag which will vary across industries, as well as across countries for a given industry, with the level of energy intensity, the relative prices of energy and other inputs, the degree of competition in product markets, the availability of government incentive programs, etc.

2.2.6 Financial Position

In addition to the factors mentioned above, the adoption of new energy-saving technology depends to a large extent on the availability of funds for investment. Conservation technologies must compete for limited capital funds with other projects like plant expansion and improvements, and pollution abatement. Particularly during recessionary periods like the early 1980s, the prospects for investment are constrained by reduced cash flow and low utilization rates. For its part, Canadian industry has tended to invest in conservation projects which are characterized by relatively short payback periods (i.e., 3 years or less) or small capital requirements.⁶

2.2.7 Government Policy

Governments have an influence on industrial energy demand through pricing policies for different energy types, incentive programs to promote energy conservation, interest rate and other macroeconomic policy, standards for environmental control, etc. The Canadian government has implemented a number of industry programs in the past, including an accelerated tax write-off for conservation and renewable energy equipment (Class 34) and the Industrial Conversion Assistance Program (ICAP) for conversions from heavy fuel oil to natural gas. In the forest products sector, the FIRE (Forest Industry Renewable Energy) program has provided up to 20 percent of the approved capital cost of facilities using biomass--wood wastes and spent pulping liquors--to replace fossil fuels.

2.2.8 Declining Resource Quality

In resource-based industries, energy use per unit of output may be affected by the depletion of higher quality resources. In mining, for example, energy requirements will tend to increase as production moves to lower grade ores and greater working depths. In wood products

and pulp and paper, depletion is reflected in increased distances between the forest and the mill, resulting in higher energy costs for transportation of wood resources.

2.2.9 Environmental Concerns

Improvements in energy efficiency may be offset by extra requirements for meeting environmental standards and controls. An example in the pulp and paper industry is given by the rise of thermal mechanical pulping. The TMP process is being adopted, in part, to alleviate the environmental problems associated with sulphite pulp production. However, it requires a significantly higher level of electric energy consumption, offsetting efficiency gains in the use of other energy types such as fuel oil.

2.3 Methodology

The analysis of energy demand in this study concentrates on a single industry: Canadian pulp and paper production. The pulp and paper industry has been chosen because it is a major energy user and because its industry association, the Canadian Pulp and Paper Association (CPPA), maintains a detailed database of annual production and energy use.

The CPPA database is disaggregated at the plant level and provides a grouping of plants by principal product type. Different products imply different processes and, hence, different energy requirements. Therefore, the database allows one to focus on specific product groups and to trace the historical trends in energy intensity for these groups.

What the CPPA database does not contain is plant-specific information on energy expenditures or, alternatively, on the unit costs (prices) of each fuel type. Furthermore, data have not been obtained relating to the costs of other production inputs such as labour and non-energy materials. Consequently, it is not possible at the plant level to assess the importance of fuel costs in total expenditures, nor to track historical movements in the cost shares of labour, energy, and other materials (i.e., factor substitution). Therefore, like the CIPEC and EMR analyses described in Chapter 1, this study looks at trends in the physical quantity of energy used at each pulp and paper mill.

2.3.1 Measures of Energy Intensity

Energy intensity is defined here in terms of thermal units (joules) of energy consumption per physical unit (tonne) of output. Consumption is measured in input energy units, as opposed to output energy units. In addition, the data do not take account of transformations in energy type within the plant, in particular, the cogeneration of electric power.

As mentioned in Chapter 1 (Section 1.1.3.1), output or useful energy is a more desirable measure than input energy because it relates production to the actual energy available for the process. However, much of the conservation effort in pulp and paper and other industries has been directed towards the conversion process—for example, the improvement of boiler efficiencies.⁷ Furthermore, a proper analysis of useful energy requires detailed data on utilization efficiencies for the various processes. In the sensitivity analyses for this study, rough estimates of aggregate combustion efficiencies are used to adjust the data from an input energy-equivalent basis to a steam-equivalent basis.

2.3.2 Aggregation of Energy Types

In order to determine total energy consumption for a given year, it is common to aggregate different energy types using their thermal conversion factors or heat values. Thus, total energy use in year t is calculated as the sum of the various fuel quantities multiplied by their heat contents:

$$E_t^* = \sum_i h_{it} F_{it}$$

where

h_{it} = heat value of fuel i for year t , in joules per quantity of fuel, and

F_{it} = quantity of fuel i for year t .

This "Btu equivalency" approach to aggregating energy is convenient for computational purposes since it requires information

only on the heat contents of component fuels. The normal practice is to apply aggregate conversion factors which are not differentiated by region or time period. While some energy types such as natural gas and fuel oil do not vary significantly in their quality (heating value), others like forest biomass can exhibit sharp swings due to differences in moisture content or composition of the wastes. In this study, mill-specific heat values are adopted, and the values for waste materials are expressed in oven-dry (i.e., without adjustment for moisture content) units.⁸ Even on this oven-dry basis, there are differences in thermal content from mill to mill.

A drawback of the common Btu aggregation is that it is based on the premise that consumers choose among fuel types according to thermal content alone. Such a premise ignores the importance of other energy "attributes"; for example, cleanliness, safety, ease of transport and storage, and the relative costs and efficiencies of end-use technologies.⁹ An alternative "economic" method of adding up energy quantities is to calculate an energy index in which the different fuel types are weighted using their relative market prices.

The underlying rationale for an economic index is that in a perfectly competitive market the relative prices of different energy types will equal their relative (marginal) costs of production; that is, market prices will reflect the true value of the fuels to society. In applying such an index to the real world, however, there are two main difficulties: (1) actual fuel prices do not necessarily correspond to these ideal prices due to the presence of market imperfections; and (2) some energy, such as self-generated hydroelectric power and combustible wastes, may not have an identifiable market value. The problem of valuing self-generated fuels is discussed below in Section 2.3.3. With regard to the first problem, market distortions can result from a number of sources. For example, the price of electricity differs from its marginal cost because of the regulation of electric utilities.

With the foregoing qualifications in mind, this study considers a price-weighted energy index as an alternative to the "Btu-equivalent" index of energy consumption. One economic index which has some theoretical and computational advantages is the Divisia quantity index of energy consumption.¹⁰ The Tornquist (discrete) approximation to the Divisia quantity index is defined as follows. The percentage change in total energy consumption is a weighted average of the

percentage change in consumption of all fuel types, where the weights refer to average expenditure shares:

$$\ln (E_t^*/E_{t-1}^*) = \sum_i w_{it} \ln (E_{it}/E_{i,t-1})$$

where w_{it} is the arithmetic mean of the i th energy type expenditure (price times quantity) share in periods t and $t-1$,

$$w_{it} = 0.5 * (w_{it} + w_{i,t-1}), \text{ and}$$

$$w_{it} = (P_{E_i t} * E_{it}) / \sum_i P_{E_i t} * E_{it}.$$

Conceptually, the Divisia index is grounded in the notion of cost-minimizing behaviour on the part of producers. Because of its theoretical foundations, the index is often used in applications examining the substitution between energy and other inputs into the production process. As applied here, the Divisia energy index is intended to capture movements in expenditure shares between higher cost and lower cost fuel types. For example, if the historical trend has been to displace higher cost fuel oil with lower cost wood wastes, then a simple Btu aggregation of input energy may show total energy use rising due to the lower efficiency of wood wastes. The Divisia index, on the other hand, should ascribe a lower weight to the contribution of wood wastes since their unit cost is significantly lower than that of fuel oil.

2.3.3 The Value of Self-Generated Energy

As mentioned above, a major problem with applying a price-weighted index of energy use to pulp and paper production is the valuation (costing) of self-generated energy, that is, own-generation of hydroelectric power, hogged fuel, and spent pulping liquors. In the case of purchased fuels and electricity, mill-specific price data are not available; however, industry-averaged market prices can be used (see Chapter 3). In the case of self-generated fuels, on the other hand, there may not be an observable market for the energy.

In order to determine accurately the costs of non-purchased fuels, it would be necessary to gather mill-level data on the relevant capital, labour, equipment, and other expenditures on these fuels. Such data are not generally available, and most mills do not maintain a separate accounting for the wage and equipment costs of wood wastes. In some instances, wood waste may be purchased from outside sources, or from nearby company sawmills, and separate billing records may be kept. In any case, the cost of these waste products is highly site-specific and time-dependent. For example, the gathering costs of hog fuel will vary with the type of waste, transportation distance, mode of transportation (truck, conveyor system from sawmill, etc.), and time of year.

Ideally, one would like to measure actual expenditures on both self-generated energy and purchased energy. For some fuel types, these expenditures would be relatively low. For example, a number of pulp and paper mills have on-site hydroelectric facilities, where the capital costs have been largely written off and unit-operating costs are minor.

In the absence of data on actual costs, the approach adopted in this study is to "value" self-generated energy in relation to the least cost alternative fuel which would be required to replace it. Other analyses of energy use in the pulp and paper industry have taken a similar approach. One analysis¹¹ valued wood wastes at the price of fuel oil, with adjustments for the lower heat value and process efficiency of wastes. A British Columbia study¹² of pulp and paper mills estimated a value for hog fuel in terms of the present value savings in fossil fuel costs over the life of a hog-burning boiler, minus the extra capital cost of the boiler, i.e., in excess of the capital cost of a comparable fossil-fuelled boiler.

There is a conceptual difficulty with valuing waste by-products on the basis of alternative fuels. This is especially the case for spent pulping liquors which are recovered in the chemical pulping process. Although the organic residues in these pulping liquors are a major source of process heat, they are burned primarily for the recovery of valuable chemicals.

The problem is less severe for hog fuel, which has grown considerably as an energy source over the past decade. Originally, the waste bark produced at the mill was largely a nuisance that had to be disposed of. As fuel prices began to escalate, wood waste emerged as a

useful energy alternative to high cost conventional fuels. Over the past decade, investments have been made in hog-fuelled boilers, and boiler efficiencies have improved as a result of better pre-drying of the waste. Typically, the constraints on further development of hog fuel as an energy source have been the capital cost of boiler conversion, concern about the availability of wastes and who controls them, and uncertainty about future energy prices.

In addition to this conceptual problem, it is difficult to value wood and process wastes because of the variability in their quality. Differences in the quality of wood waste can be attributed to such factors as moisture content, wood species, and composition of the wastes (bark, sawdust, etc.). The energy recovered by burning pulping liquors depends on the yield of the fibre in the pulping process. The lower the yield, the greater the organic content of the liquor and, thus, the greater the recoverable heat.

For the purposes of this study, self-generated hydroelectricity is assumed to be valued at the cost of purchasing power from the provincial electric grid, that is, at the industry average electricity rate. The value of hog fuel and spent pulping liquors is tied to the price of the predominant fossil fuel source of the mill, either natural gas or residual fuel oil. Unlike the treatment of self-generated hydro, a discount is applied to the price of the alternative fuel, to account for the inconvenience cost of waste materials (e.g., ash disposal), variability in their heat content, and other quality-related factors.¹³

Given the difficulties in valuing wood and process wastes, two adjustments are made to the analysis. First, the energy indexes are calculated both with and without spent pulping liquors, since this energy source is such an integral part of the production process. Second, in order to show the sensitivity of the index to different prices for hog fuel and pulping liquors, different discounts are applied to the cost of the alternative fuel--20 percent, 50 percent, and 80 percent. While these discount factors are fairly arbitrary, they demonstrate a range of "reasonable" costs for wood waste.¹⁴

2.3.4 Calculating Energy Intensity

In the analysis in Chapter 4, Btu and Divisia indexes of energy consumption are calculated for different samples of pulp and paper

mills. In each case, the index of total input energy is computed relative to the CPPA base year of 1972. Then, an energy-intensity index is defined as the level of the energy index in each year divided by a corresponding index of physical production. Finally, this intensity index is tracked over the historical period (1976-1984) to observe any trend in the efficiency of aggregate energy use.

In terms of sensitivity analysis, two variations are made on the study methodology. First, the Btu index of input energy is adjusted for the combustion efficiencies of the component fuels. That is, the energy inputs of all fuels are converted to a "steam-equivalent" basis. Second, in the case of newsprint mills, boiler demand for electricity is separated from motive demand. This is done to highlight the impact on total energy use of Hydro-Quebec's boiler conversion program.

To summarize, this chapter has outlined a methodology for examining trends in energy intensity for the Canadian pulp and paper industry. In the next chapter, we describe the detailed energy use, production and pricing data which will be used to estimate these historical relationships.

Footnotes

¹Roger W. Sant, "Thinking Ahead - 'Least-Cost' Marketing Approach to the Energy Problem Suggests Promising Product and Technological Opportunities," Harvard Business Review, May-June 1980, p. 6.

²Middleton Associates, "Energy Conservation: Retrospect and Prospect," Background Paper Prepared for a Seminar Sponsored by the Conservation and Renewable Energy Branch, Energy, Mines and Resources Canada, Ottawa, December 1981.

³Ibid., p. 3.

⁴For an example of this factor cost approach see Blaine Kennedy, "Analysis of Energy Productivity and Energy as Cost Factor of Production in Canadian Industry," (Ottawa: Industrial Energy Division, Energy, Mines and Resources Canada, Work in Progress.

⁵For example, between 1962 and 1984 the four most energy-intensive industries exhibited the following declines in their shares of total industrial RDP:

Pulp and Paper	4.2 to 4.0 percent
Cement	0.5 to 0.3 percent
Smelting and Refining	2.0 to 1.5 percent
Iron and Steel	2.9 to 2.4 percent

Hallivell and Valade, Industrial Energy Demand: A Review of Recent Trends (Ottawa: Market Analysis and Statistics Division, Energy, Mines and Resources Canada, 1984), p. 27; and Statistics Canada, Gross Domestic Product by Industry, Catalogue 61-213.

⁶CIPEC Task Force Council, Canadian Industry Program for Energy Conservation: 1984 Report (Ottawa: Energy, Mines and Resources Canada, 1984), p. 4; and Graham T. Armstrong, "Conservation Energy - Potential and Practice in Canada," Presentation to the Conservation Energy Seminar Series, Office of Energy Conservation, Saskatchewan Department of Mineral Resources, Regina, June 1980. It has been argued that the use of a payback criterion for evaluating investment decisions constitutes a barrier to more widespread use of conservation technologies, and that industries apply a stricter rate-of-return requirement to these technologies than to plant expansion projects. See for example Armstrong, pp. 27-28 and Steven G. Diener, "Comparative Resource Costs and the Economic Limits to Energy Conservation in Canada," Paper Presented to the IAEE Conference on International Energy Issues, Cambridge, England, June 1980.

⁷In other words, conservation measures have been aimed at reducing input energy requirements by increasing efficiency. Therefore, a measurement of output energy may not indicate conservation in energy use through time.

⁸The "oven-dried" heat value of wood waste differs from its "as-fired" heat value according to the percentage of moisture content in the waste. Moisture content affects not only the as-fired heat value but also the combustion efficiency of the fuel since water must be vaporized before combustion can take place.

⁹For a discussion of these attributes and a lucid description of the problems of aggregating energy consumption, see Ernst R. Berndt, "Aggregate Energy, Efficiency and Productivity Measurement," Annual Review of Energy, Volume 3, 1978, pp. 225-273.

¹⁰See Appendix A for some detail on the Divisia Energy Index.

¹¹Rodger R. Arola, "Wood Fuels - How Do They Stack Up?" Energy and the Wood Products Industry, Proceedings of a Conference by the Forest Products Research Society, Atlanta, November 1976, p. 39.

¹²Alan J. Cox, "An Economic Evaluation of the Use of Wood Wastes to Generate Heat and Electricity at Pulp and Paper Mills in British Columbia," Resources Paper No. 20 (Vancouver: Programme in Natural Resource Economics, University of British Columbia, August 1978).

¹³A more detailed discussion of the pricing of non-purchased fuels is contained in Appendix B.

¹⁴A brief survey of industry contacts indicated a range for the unit cost of hog fuel of between \$5.00 and \$30.00 per tonne. Assuming a cost of \$30.00 per tonne and an oven-dry heat content of 20 MJ/kg, the resulting energy cost of hog fuel would be \$1.50 per GJ. This value is approximately 50 percent of the 1984 price of natural gas in British Columbia, and approximately 30 percent of the 1984 price of heavy fuel oil. See Appendix C, Tables 1b and 1c.



Chapter 3

DATA

This chapter documents the data which will be used in the analysis of energy-intensity trends in the Canadian pulp and paper industry (Chapter 4). The chapter begins with a description of a mill-specific database obtained from the Canadian Pulp and Paper Association (CPPA) in Montreal. This database provides the source of information for historical energy consumption by fuel type, as well as for annual production of output. Subsequently, a discussion is included on pricing data required for computing expenditure shares for each of the fuels. Together, these energy consumption, production, and pricing data allow for the calculation of the energy-intensity indexes outlined in Chapter 2.

3.1 Energy Consumption

The Canadian Pulp and Paper Association collects data on energy consumption as part of a quarterly survey of member companies. The survey is conducted using a questionnaire developed by the CPPA Energy Steering Committee, a collection of industry representatives. In 1984, there were 64 companies and 123 mills in the survey, accounting for an estimated 98 percent of total pulp, paper, and paperboard production.¹

Energy-use data are gathered for 13 different purchased and self-generated energy types:

1. Purchased electricity for motive use
2. Purchased electricity for boiler use
3. Natural gas
4. Residual fuel oil
5. Distillate fuel oil
6. Liquefied petroleum gases (LPGs)
7. Lignite coal and coke
8. Other purchased (steam)
9. Hog fuel (other)
10. Hog fuel (self-generated)
11. Spent pulping liquors (solids)
12. Own hydraulic power
13. Own hydro-mechanical power

Self-generated hog fuel refers to solid wood wastes produced on site at the pulp mill, through debarking and chipping operations. Other hog fuel denotes bark, sawdust, and shavings from nearby sawmills or other wood products operations, generally within the same company. Own hydraulic power is electricity generated on-site at company-owned hydroelectric facilities, and own hydro-mechanical power relates to direct drive grinders.

For each fuel type, the companies report volume of energy consumed (kilowatt-hours of electricity, cubic metres of natural gas, etc.), heating value to convert to thermal equivalency (joules per kilowatt-hour, joules per cubic metre, etc.), and the resulting amount of energy input (joules). Heating values may vary from mill to mill and, for a given mill, from year to year depending on the quality of the fuel used. The values for hog fuel and spent pulping liquors are expressed in joules per oven-dry kilogram, and are not adjusted for moisture content (joules per as-fired kilogram) which is highly variable. In most cases, the energy inputs reported for these fuels have been derived by measuring backwards, i.e., by observing boiler output energy and applying an estimated boiler efficiency to convert to input energy requirements.

Since all consumption is reported on this input energy basis, there is no information collected on the combustion efficiencies of different fuels in their conversion to process steam. Nor do the data capture transformations within the mill from one energy type to another. Thus, there is no accounting for electricity production from on-site cogeneration facilities. Rather, this final electricity demand (plus losses) is embodied in the fossil fuels and wood wastes which produce steam for the cogeneration process.

The CPPA survey results are aggregated by major product into 12 different product groupings: (1) sulphite pulp for making rayon, etc.; (2) sulphite pulp for paper or paperboard; (3) bleached kraft market pulp; (4) bleached kraft pulp for paper or paperboard; (5) newsprint with integral sulphite pulp; (6) newsprint with integral kraft pulp and paper or paperboard; (7) newsprint with integral chemical pulp; (8) paperboard; (9) fine, specialty and miscellaneous paper and non-integrated; (10) corrugating medium; (11) building board; and (12) groundwood market pulp. The two largest of these product groupings are integrated newsprint with sulphite pulp (26 mills) and bleached kraft market pulp (25 mills).

The advantages of the CPPA database can be summarized as follows:

- the survey has an extensive coverage;
- energy use is reported at the mill level;
- both purchased and self-generated energy types are accounted for;
- the breakdown by major product recognizes the differences in energy requirements across products and processes (e.g., newsprint versus bleached kraft market pulp, kraft versus groundwood pulp);
- motive and boiler electricity are separated, illustrating the impact of Hydro-Quebec's incentive program for conversion to electric boilers; and
- the data are reported by the energy-using companies themselves--i.e., by individuals in the energy management field--and are reviewed by industry experts at the CPPA.

3.1.1 CERI Sub-sample

For the purposes of this study, data have been obtained for the two largest product groups: bleached kraft market pulp and newsprint with integral sulphite pulp. Not only do these two groups make up a substantial share of total Canadian pulp and paper production, but they provide an interesting comparison by virtue of their different energy-using characteristics.

In providing CERI with data, the CPPA has concealed the identities of the reporting mills, as well as of the companies operating them. The mills have been numbered arbitrarily by CERI, and the energy intensity trends presented in Chapter 4 are for all mills (newsprint or kraft) taken together.

3.1.1.1 Bleached Kraft Pulp Mills

In order to generate a consistent sample, the 25 bleached kraft pulp mills have been reduced to 15 in number. Two mills have been excluded because they produced a significant amount of other product (e.g., sulphite pulp) during the historical period.² Another eight mills have been dropped either because they were not in the survey

sample for all years (5 mills) or because they reported incomplete data for any given year (3 mills).

After these exclusions, the CERI sub-sample of kraft pulp mills accounts for just under 60 percent of 1984 production and energy use contained in the CPPA survey sample.

	<u>CPPA Sample (25 Mills)</u>	<u>CERI Sub-Sample (15 Mills)</u>	<u>CERI/CPPA (%)</u>
1984 Production (000 tonnes)	4930.6	2832.8	57
1984 Total Energy Inputs (FJ)	214.9	127.2	59

3.1.1.2 Integrated Newsprint Mills With Sulphite Pulp

The 26 newsprint mills in the CPPA sample were reduced to 19 mills after exclusions for substantial other product (3 mills) and reporting of incomplete data for any year (4 mills). The resulting sub-sample represents about three-quarters of 1984 output and energy inputs contained in the CPPA sample:

	<u>CPPA Sample (26 Mills)</u>	<u>CERI Sub-Sample (15 Mills)</u>	<u>CERI/CPPA (%)</u>
1984 Production (000 tonnes)	5958.1	4461.0	75
1984 Total Energy Inputs (FJ)	117.2	86.5	74

3.2 Production

In addition to input energy, the CPPA database contains annual production data by mill and type of product, in physical tonnes of output. (In earlier years, both output and energy consumption were reported in imperial units, but have been converted to metric units for this analysis.) Where the mill produces output other than kraft pulp or newsprint, all products are added together since reported energy use relates to total production at the site.

3.3 Fuel Prices

The CPPA survey does not collect information concerning the mills' expenditures on various types of energy. This information is required for calculating the Divisia index of energy consumption (see Chapter 2, Section 3.2), which weights the contribution of each fuel type to total energy consumption by its share of total energy expenditures. The only published source of fuel expenditures at the industry level is Statistics Canada's Catalogue 57-208, Consumption of Purchased Fuel and Electricity (CPFE). This publication contains value and quantities of purchased energy to the 4-digit SIC level for the following categories: coal and coke, natural gas, gasoline, kerosene, diesel fuel oil, light fuel oil, heavy fuel oil, LPGs, purchased electricity, and other.³

For this study, a unit price has been determined for each fuel by dividing the value of expenditure by the fuel volume, with adjustments for conversion to constant (1971) dollars and thermal energy units.⁴ The price of heavy fuel oil is assigned to residual fuel oil and distillates. Light fuel oil, diesel fuel oil, kerosene and gasoline, are priced on the basis of light fuel oil alone. Since the CPFE data are only available through 1983, prices for 1984 have been extrapolated using a average industrial fuel prices from Energy, Mines and Resources Canada's Interfuel Substitution and Demand (IFSD) database.⁵ These prices are differentiated by province but are for the industrial sector as a whole, i.e., they are not industry-specific.

Because the identities and locations of the sample mills have been concealed, it is not possible to assign the appropriate provincial fuel prices to each mill. This is a problem for the sample of bleached kraft pulp mills which is known to be distributed among several western and eastern provinces. For ease of analysis, the CPPA has divided the sample into eastern and western regions, with the dividing line being the Ontario-Manitoba border.⁶ British Columbia energy prices are then assigned to the western mills, and Quebec prices to the eastern mills. The one exception is eastern natural gas prices which are based on Ontario prices, since the majority of natural gas use in eastern pulp and paper production occurs in that province.

In the case of integrated newsprint, all mills but one are known to be located in eastern Canada. Consequently, the sample is treated as being entirely eastern, and the pricing assumptions are as indicated above for eastern kraft pulp mills.

Some qualifications should be noted with respect to the purchased fuel-pricing data. First, the 1984 prices have been estimated using average industrial prices and, therefore, should be viewed with some caution. Second, even with industry-level detail, the use of aggregate pulp and paper fuel prices is not necessarily relevant for an individual mill. Ideally, one would prefer mill-level prices or expenditures to account for differences in the negotiated prices for various fuels, changes in availability from year to year, etc. Nevertheless, industry-level prices should capture basic trends in the expenditure shares of competing fuels, i.e., shifts out of higher cost into lower cost fuels.

There are a number of difficulties which arise when assigning prices to non-purchased energy. These difficulties, and the assumptions adopted for this study, are discussed in Chapter 2, Section 3.3. Detailed tables on the prices of purchased energy are presented in Appendix C.

Footnotes

¹CIPEC Task Force Council, Canadian Industry Program for Energy Conservation: 1984 Report (Ottawa: Energy, Mines and Resources Canada, October 1985). The energy survey is used in the annual reporting by the Pulp and Paper Energy Conservation Task Force to the CIPEC Task Force Council.

²Because a significant number (7) of integrated newsprint mills reported some amount of other product, those mills with less than 85 percent of production made up by the principal product (kraft pulp or newsprint) were excluded from the sample.

³In the CPFE reporting, "Other" refers to energy sources such as purchased steam, uranium, wood (but not wood wastes) and, starting in 1983, kerosene. Only a cost value is reported for these fuels because of the heterogeneity of their quantities. Therefore, a unit price cannot be determined for the category "Other purchased (steam)" in pulp and paper, and a price value must be estimated. See Appendix B.

⁴See Appendix C.

⁵The IFSD database is maintained by the Energy Market Analysis and Statistics Division of EMR, and contains data on sectoral energy use, fuel prices, etc.

⁶According to this definition, the CPPA sample of 25 bleached kraft mills consists of 14 western and 11 eastern mills. The CERI sub-sample of 15 mills consists of 11 western and 4 eastern mills. Therefore, it should be noted that the omission of mills from the CPPA sample has imparted a western bias to the CERI sub-sample.



Chapter 4

RESULTS

This chapter presents the results of an analysis of energy intensity changes in the Canadian pulp and paper industry. A brief description of the two relevant production processes--kraft pulping and newsprint manufacture--is provided, followed by a general discussion of energy use in pulp and paper production. Finally, the trends in energy intensity are analyzed for the samples of bleached kraft pulp mills and integrated newsprint mills.

4.1 Pulp and Paper Processes

There has been a trend in pulp and paper production towards large, "integrated" operations, where raw timber is brought to the mill and processed on site into finished paper products. Non-integrated operations, on the other hand, are engaged in the production of market pulp from timber or in the manufacture of paper products from purchased pulp.

Figure 4.1 summarizes the manufacturing process in an integrated pulp and paper product mill. On its arrival at the site, the timber is debarked and prepared for pulping, the process by which the wood is reduced to a fibrous mass. Mechanical pulping involves grinding logs against a revolving stone (stone groundwood process), or shredding and grinding chips between the rotating discs of a refiner (refiner mechanical process). In chemical pulping, wood chips are cooked in chemicals to dissolve the lignin which serves as a bonding agent for the fibres. The major chemical process is the kraft process which uses sodium sulphide (Na_2S) and sodium hydroxide (NaOH) to produce a strong dark-coloured paper. Other chemical processes include the neutral sulphite process and the acid sulphite process. In addition, there are combinations and variations of these different processes--chemi-mechanical pulping, thermal mechanical pulping, etc.

After chemical pulping, the pulp stock is washed, screened, thickened and refined in preparation for the paper machine. It may also undergo bleaching prior to this stage. In paper manufacture, the

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graph TD
    LOG[LOGS] --> DEBARKING[DEBARKING]
    DEBARKING --> BARK[BARK]
    DEBARKING --> SPLIT[Splitwood]
    SPLIT --> CHIPPING[CHIPPING]
    CHIPPING --> CHEMICAL_PULPING[CHEMICAL/CHEN-BECH. PULPING]
    CHIPPING --> MECHANICAL_REFINING[MECHANICAL REFINING]
    CHEMICAL_PULPING --> CHEMICAL_PULP[CHEMICAL PULP]
    CHEMICAL_PULP --> WASHING[WASHING]
    WASHING --> BLEACHING[BLEACHING]
    BLEACHING --> BLEACHED_PULP[Bleached Chemical Pulp]
    BLEACHED_PULP --> REFINING[REFINING]
    WASHING --> SPENT_LIGNIN[Spent Pulping Liquor]
    SPENT_LIGNIN --> CHEMICAL_RECOVERY[CHEMICAL RECOVERY]
    CHEMICAL_RECOVERY --> PULPING_LIGNIN[Pulping Lignin]
    PULPING_LIGNIN --> CHEMICAL_PULPING
    MECHANICAL_REFINING --> MECHANICAL_PULP[Mechanical Pulp]
    MECHANICAL_PULP --> BLENDING[PULP BLENDING]
    REFINING --> BLENDING
    REFINING --> UNBLEACHED_PULP[Unbleached Chemical Pulp]
    UNBLEACHED_PULP --> REFINING2[REFINING]
    REFINING2 --> BLENDING
    BLENDING --> STOCK_PREP[STOCK PREPARATION]
    STOCK_PREP --> PAPER_SECTION[PAPER SECTION]
    PAPER_SECTION --> MECHANICAL_PRESS[MECHANICAL PRESS]
    MECHANICAL_PRESS --> DRYING[DRYING]
    DRYING --> FINISHING[FINISHING]
    FINISHING --> PRODUCTS[PRODUCTS]
    GRINDING[GRINDING] --> BLENDING
    GRINDING --> MECHANICAL_PULP
  
```

SOURCE: Energy and Environmental Analysis, Inc., Industrial Energy Productivity Project - Final Report: The Pulp and Paper Industry, DOE/CS/40151-1, February 1983.

fibres are suspended in water onto a fine-woven moving screen. They form a mat which is passed through presses to remove the water, dried by evaporation, and subjected to any required finishing procedures. The most important paper product, newsprint, is a printing paper made primarily from mechanical pulp.

4.2 Energy Use in Pulp and Paper Processes

Pulp and paper production requires substantial amounts of steam and electricity for its various processes. The largest overall application of energy is in the generation of steam to serve thermal, mechanical, and electrical (cogeneration of heat and electric power) processes. This steam is generated primarily through the combustion of conventional fossil fuels, organic residues (lignin and hemicellulose) in spent pulping liquors, and hog fuel in the form of bark, chips, and sawdust. The burning of residues in pulping liquors is a by-product of chemical recovery, and constitutes a major source of steam energy for the kraft pulping process.

Electricity requirements are met through outside purchases, cogeneration with process steam, and on-site hydroelectric and thermal power facilities. The majority of this electric power is destined for motive use, with the remainder going largely to lighting applications.

To the extent possible--given maintenance requirements and product supply and demand conditions--pulp and paper mills are operated continuously throughout the year. That is, during a "typical" year in which supply and demand are matched, a mill will tend to run 24 hours per day, 350 days or so per year, with a few weeks of planned maintenance. As a result, process heat requirements are usually continuous and electricity load factors tend to be 90 percent or more.

There is a wide variety of measures for promoting energy conservation in the pulp and paper industry. A readily available source of conservation is housekeeping activities such as improved operating techniques, better energy system maintenance, and elimination of wastage. Depending on the availability of capital, pulp and paper mills may also invest in new energy-saving technologies and equipment (plant retrofits, process computer controls on paper machines, etc.). For example, new high-speed paper machines are being introduced which increase electricity requirements, but cut down on steam use, as a

result of better pressing. Typically, energy-saving technologies tend to favour conservation in steam use, since electric power requirements are relatively fixed in the existing process and equipment stock.¹

In addition to these measures, energy efficiency can be improved through the displacement of purchased energy by lower cost wood and process wastes. Table 4.1 shows the trends in purchased energy use per tonne of product for the entire CPPA sample of pulp and paper mills. The CPPA data indicate a 27 percent drop in the unit (per tonne) consumption of all purchased energy between 1972 and 1984, and a 60 percent drop in the unit consumption of heavy fuel oil alone. While the table does not report self-generated energy use, CPPA survey results show a rise in the share of hog fuel and spent pulping liquors from 48 percent of "total fuel use" in 1972 to some 64 percent in 1984.²

Another trend which is evident in the aggregate energy data is the increase in purchased electricity consumption. Two noteworthy factors have contributed to this growth in electricity requirements: (1) Hydro-Quebec's boiler conversion program, accounting for the jump in unit electricity demand in 1984; and (2) the development of thermal mechanical pulping capacity. Between 1975 and 1984, total Canadian TMP capacity grew from 620 to 12 275 air-dry tonnes per day.³ This represented 34 percent of mechanical pulping capacity and 15 percent of total pulping capacity in 1984.

In the TMP process, the wood chips are steamed under pressure for a few minutes, to be softened, and then are passed through a refiner. The result is a stronger pulp relative to that produced by other mechanical pulping methods, i.e., stone groundwood and refiner mechanical pulping. In addition, TMP offers overall cost savings due to a lower requirement for chemical pulp in newsprint manufacture, and the potential for using cheaper wood sources such as shavings and sawdust. However, thermal mechanical pulping is considerably more energy-intensive, requiring up to 80 percent more electrical energy than the stone groundwood process.⁵

4.3 Analysis of Energy Use in Kraft and Newsprint Mills

By way of introduction, Tables 4.2 and 4.3 and Figures 4.2 through 4.5 present data on historical energy consumption for each of

TABLE 4.1

PURCHASED ENERGY USE - CPPA SURVEY
OF PULP AND PAPER MILLS
(gigajoules per tonne of product)

	Electricity	Heavy Fuel Oil	Distillates	Natural Gas	Coal	Other ^a	Total
1972	4.5	9.0	0.3	3.8	0.7	0.2	18.5
1977	4.7	7.4	0.4	4.2	0.6	0.3	17.8
1978	4.7	7.0	0.3	3.9	0.6	0.2	16.7
1979	4.4	6.5	0.4	4.0	0.5	0.1	15.9
1980	4.5	6.0	0.4	3.9	0.5	0.2	15.5
1981	4.8	5.9	0.3	3.9	0.4	0.2	15.5
1982	5.0	5.6	0.3	4.0	0.5	0.2	15.6
1983	5.0	4.5	0.2	3.5	0.5	0.1	13.8
1984	5.7	3.6	0.3	3.5	0.4	0.0	13.5

SOURCE: CPPA 1985 Reference Tables.

^aPurchased steam and propane.

TABLE 4.2
BLEACHED KRAFT PULP HILL SAMPLE -
ENERGY CONSUMPTION BY FUEL TYPE^a
(input energy units)

	Purchased Electricity			Natural Gas			Residual Fuel Oil			Distillates & LPGs			Coal, Coke, & Other		
	PJ	XGR ^b	ZShare ^c	PJ	XGR	ZShare	PJ	XGR	ZShare	PJ	XGR	ZShare	PJ	XGR	ZShare
1972	3.7		3.0	16.2		13.2	16.7		13.6	0.6		0.5	2.6		2.1
1976	4.2	14.2	3.1	19.1	17.7	14.0	15.0	(10.3)	11.0	0.6	(3.1)	0.5	2.6	(24.4)	1.4
1977	4.2	(2.1)	3.1	17.6	(8.0)	13.2	11.7	(22.2)	8.7	0.7	16.5	0.5	2.9		1.7
1978	4.6	4.7	3.0	19.0	8.0	12.9	12.3	5.4	8.4	0.6	(13.4)	0.4	2.2	12.9	1.7
1979	4.5	4.5	3.2	19.2	1.2	13.5	12.9	5.1	9.1	0.8	19.8	0.5	1.9	1.2	1.5
1980	4.5	(1.4)	3.1	21.3	10.8	14.6	11.5	(11.1)	7.9	0.7	(9.5)	0.5	2.1	(14.3)	1.4
1981	4.1	(7.9)	3.2	17.8	(16.4)	13.6	10.7	(6.5)	8.2	0.8	15.5	0.6	2.1	7.6	1.4
1982	3.8	(7.5)	3.0	17.0	(4.2)	13.5	9.3	(12.9)	7.4	0.6	(25.3)	0.5	1.8	1.2	1.6
1983	3.8	0.0	2.9	15.3	(10.2)	11.8	8.3	(10.9)	6.4	0.4	(26.7)	0.3	2.0	(13.3)	1.4
1984	4.3	12.0	3.4	14.3	(6.5)	11.2	8.4	0.7	6.6	0.5	5.1	0.4	2.2	9.8	1.5
														8.5	1.7

	Mog Fuel			Pulping Liquors			Self-Generated Hydraulic Power			Total Energy		
	PJ	XGR	ZShare	PJ	XGR	ZShare	PJ	XGR	ZShare	PJ	XGR	ZGR
1972	15.0		12.1									
1976	22.6	51.1	16.6	68.2		55.3	0.3		0.3			
1977	23.7	5.1	17.8	72.1	5.6	31.8	0.9		0.9			
1978	27.1	14.2	18.5	73.0	1.4	34.6	0.3		0.3	180.9		0.6
1979	25.4	(6.3)	17.8	81.0	10.9	55.1	0.3		0.3	(70.7)		0.2
1980	23.8	(6.3)	16.3	77.4	(4.4)	34.4	0.2		0.2	16.1		0.2
1981	20.6	(13.5)	15.8	82.2	6.1	36.2	0.2		0.2	(29.2)		0.1
1982	23.0	11.7	18.2	74.4	(9.4)	36.9	0.2		0.2	(5.1)		0.2
1983	26.4	14.6	20.4	70.4	(5.4)	35.8	0.2		0.2	4.0		0.2
1984	23.6	(10.7)	18.5	73.2	4.0	36.5	0.2		0.2	0.9		0.2
				73.6	0.5	37.8	0.5		0.5	(4.0)		0.4
										124.4		
										127.2		

^aSample of 15 mills out of 25 in CPPA product group.

^bGrowth rate in energy (PJ) from previous year.

^cEnergy (PJ) of fuel type as percentage of Total Energy.

TABLE 4.3

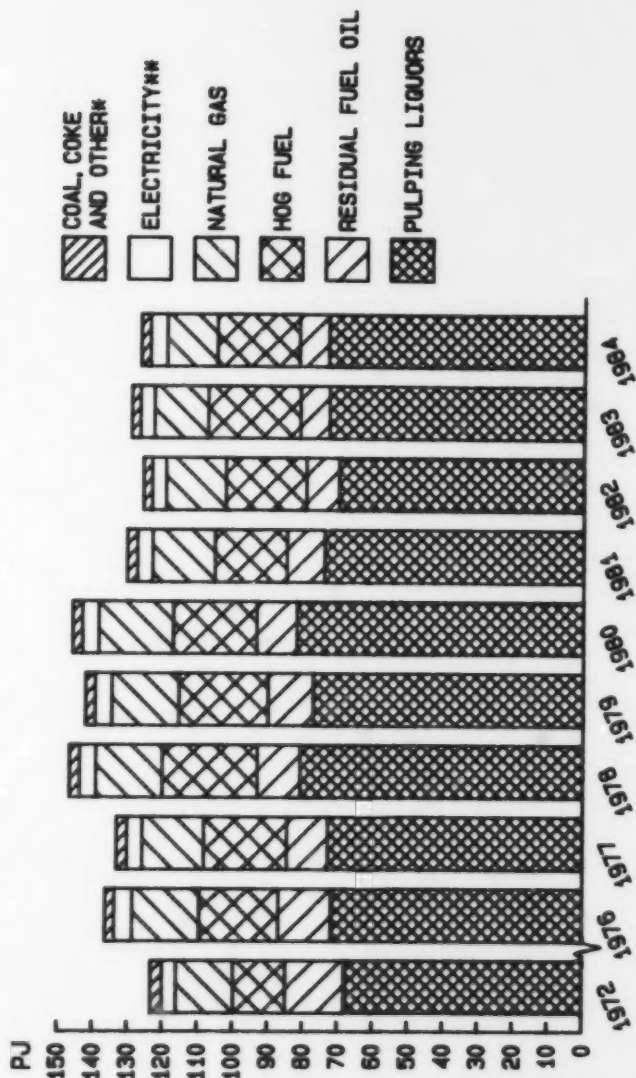
INTEGRATED NEWSPRINT MILL SAMPLE -
ENERGY CONSUMPTION BY FUEL TYPE
(input energy units)

	Purchased Electricity			Natural Gas		Residual Fuel Oil			Distillates & LPGs			Coal, Coke, & Other		
	PJ	ΣGR	ΣShare	PJ	ΣGR	PJ	ΣGR	ΣShare	PJ	ΣGR	ΣShare	PJ	ΣGR	ΣShare
1972	29.6	34.7	10.5	12.3	28.2	21.1	(25.3)	31.0	2.0	(11.2)	2.3	5.6	6.6	6.6
1976	32.1	8.2	39.6	12.5	18.4	15.4	11.1	21.1	1.8	(11.2)	2.3	5.1	(8.9)	6.3
1977	33.6	4.7	40.5	11.2	(10.6)	13.5	21.2	0.7	25.6	1.8	2.7	4.5	(12.3)	5.4
1978	34.5	2.8	36.4	12.4	11.5	13.8	22.6	6.5	25.1	2.2	19.4	2.4	5.3	5.9
1979	33.5	(3.1)	37.4	12.1	(2.4)	13.6	22.0	0.0	24.7	2.4	12.1	2.7	4.5	(15.4)
1980	33.9	1.3	36.5	11.3	(6.7)	12.9	22.3	1.2	25.3	2.3	(6.1)	2.6	3.7	(16.2)
1981	35.7	5.2	40.1	10.2	(10.1)	11.4	22.8	2.2	25.6	2.3	0.0	2.6	(29.5)	3.0
1982	32.6	(8.7)	40.8	8.6	(14.8)	10.9	20.9	(8.1)	26.2	1.8	(20.3)	2.3	2.3	(14.2)
1983	34.8	6.8	43.1	7.7	(10.8)	9.6	16.9	(19.1)	21.0	1.7	(7.1)	2.1	3.3	4.0
1984	39.9	14.7	46.1	9.7	25.1	11.2	13.0	(23.4)	13.0	1.7	3.1	3.2	(1.5)	3.7

	Log Fuel			Pulping Liquors			Self-Generated Hydraulic Power			Total Energy		
	PJ	ΣGR	ΣShare	PJ	ΣGR	ΣShare	PJ	ΣGR	ΣShare	PJ	ΣGR	ΣShare
1972	5.3	(4.5)	6.2	0.6	(43.3)	0.7	3.6	4.2	4.2	85.5	(5.3)	85.5
1976	5.1	13.2	6.9	0.7	110.9	0.9	3.1	(14.4)	3.8	81.0	2.4	81.0
1977	7.7	38.7	8.8	0.8	9.0	0.9	4.2	1.5	5.0	82.9	8.5	82.9
1978	8.6	10.8	9.8	0.8	7.5	0.9	5.1	22.7	5.8	90.0	(0.7)	90.0
1979	8.7	(1.0)	9.9	0.8	(3.0)	0.9	5.1	(2.3)	5.8	89.3	(1.4)	89.3
1980	10.0	14.5	11.2	0.5	(43.7)	0.5	5.0	(1.5)	5.6	88.1	1.0	88.1
1981	9.0	(9.7)	11.3	0.3	(39.1)	0.3	4.3	(13.5)	5.4	89.0	(10.3)	89.0
1982	11.0	22.2	13.6	0.9	231.9	1.1	4.6	2.5	5.5	79.8	1.1	79.8
1983	14.1	28.5	16.3	0.9	(1.2)	1.0	4.0	(8.8)	4.7	80.7	7.2	80.7
1984										86.5		86.5

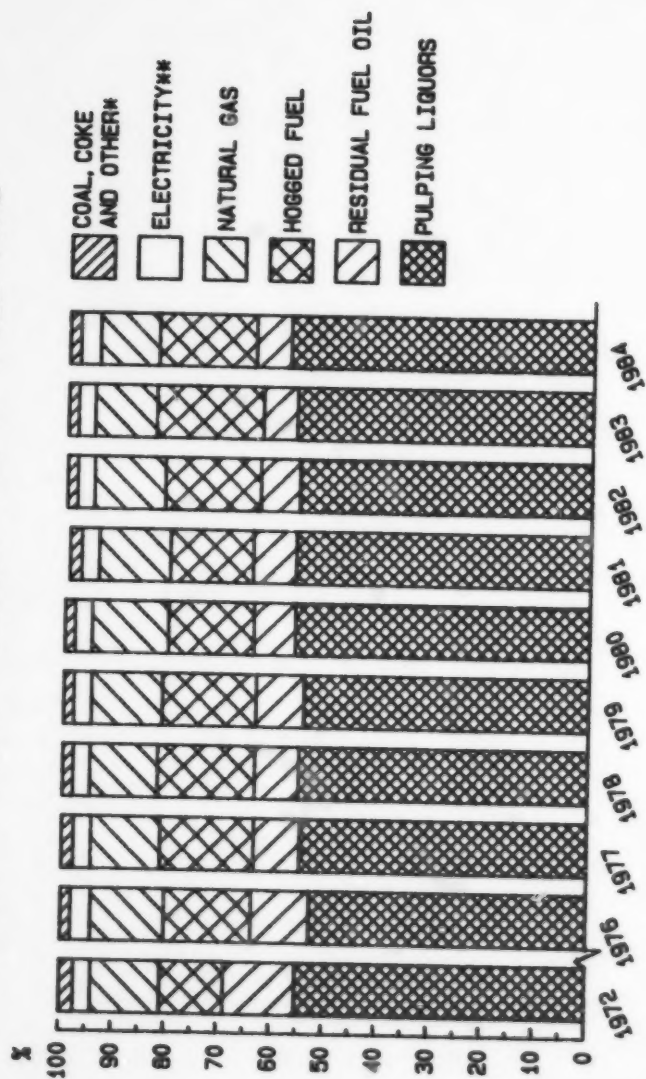
Example of 19 mills out of 26 in GPPA product group.
Borough rate in energy (PJ) from previous year.
Energy (PJ) of fuel type as percentage of Total Energy.

FIGURE 4.2
SAMPLE OF BLEACHED KRAFT PULP MILLS (15)
ENERGY CONSUMPTION BY FUEL TYPE



Source: CPPA Database
*Includes distillates, LPGs and steam.
**Purchased and self-generated hydro.

FIGURE 4.3
SAMPLE OF BLEACHED KRAFT PULP MILLS (15)
SHARES OF ENERGY CONSUMPTION BY FUEL TYPE

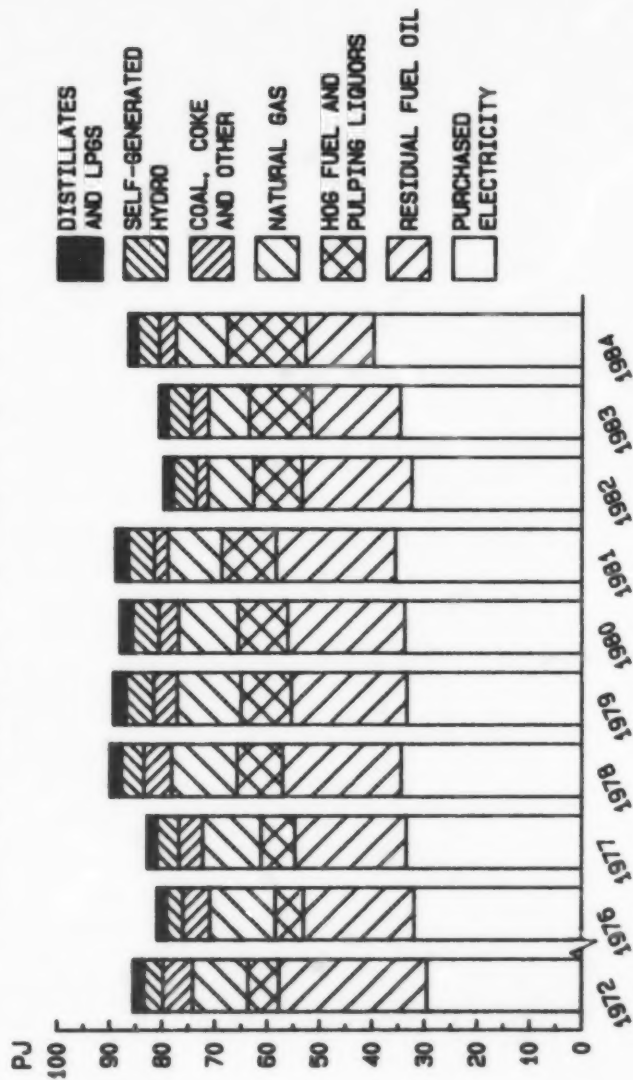


Source: CPPA Database

Note: *Includes distillates, LPGs and steam.

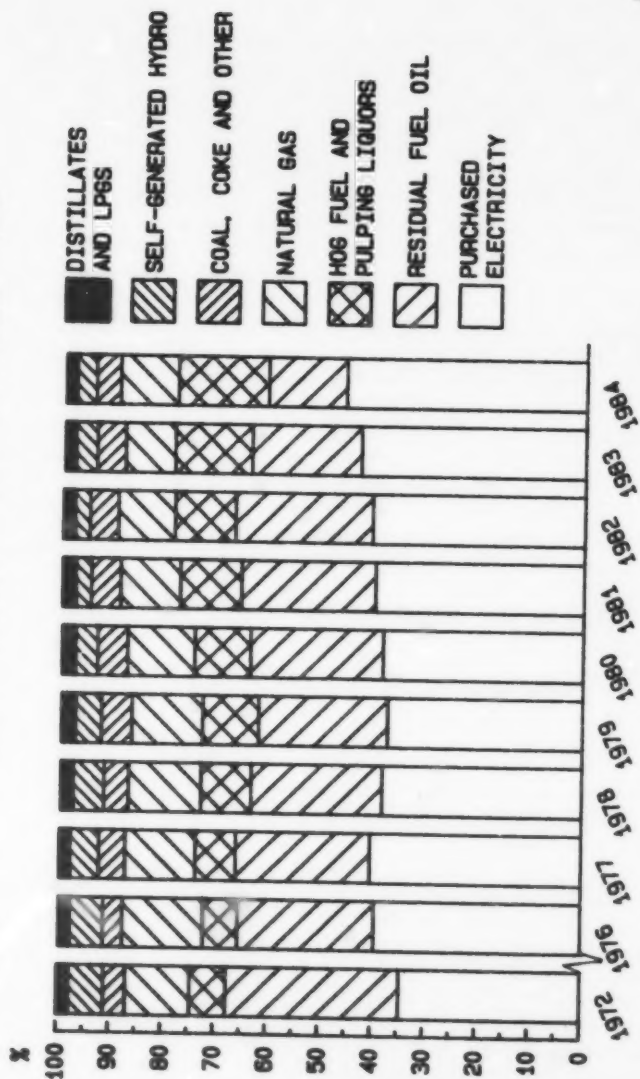
**Purchased and self-generated hydro.

FIGURE 4.4
SAMPLE OF INTEGRATED NEWSPRINT MILLS (19)
ENERGY CONSUMPTION BY FUEL TYPE



Source: CPPA Database

FIGURE 4.5
SAMPLE OF INTEGRATED NEWSPRINT MILLS (19)
SHARES OF ENERGY CONSUMPTION BY FUEL TYPE



Source: CPPA Database

the two mill samples--bleached kraft market pulp (15 mills) and newsprint with integral sulphite pulp (19 mills). The tables report energy input (petajoules) by fuel type, total energy input, and the share of each fuel in total energy. In 1984, the unit-energy consumption of all fuels and electricity was 44.9 gigajoules (GJ) per tonne for the bleached kraft pulp sample and 19.4 GJ per tonne for the integrated newsprint sample. The corresponding consumption values for purchased energy only (excluding self-generated fuels) were 10.4 and 15.1 GJ per tonne, respectively. Therefore, on the basis of total input energy, kraft pulping is roughly twice as energy-intensive as newsprint manufacture; however, in terms of purchased fuels and electricity only, production of newsprint is the more energy-using process.

The difference in energy use between the two product groups is particularly evident in the consumption of purchased electricity and wood and process wastes. In bleached kraft pulp production, almost 70 percent of input energy requirements are met by wastes, and purchased electricity accounts for only 3 percent of total inputs (Table 4.2). In newsprint manufacture, the largest proportion of total input energy is made up by electricity purchases, and a much smaller amount of energy is recovered in the form of combustible wastes (Table 4.3). This greater "energy recovery" can be attributed directly to the nature of the production process, in particular, to the recovery of pulping chemicals.

Table 4.2 shows the importance of spent pulping liquors as an input to bleached kraft pulp production. Pulping liquors were the source of some 53 to 58 percent of total energy requirements over the 1976-1984 period. The increase in residual fuel oil (RFO) share in 1979 can be attributed to one western mill which effectively doubled its reported fuel oil consumption in that year.

In kraft pulp production, it would appear that much of the decline in the residual fuel oil share of total energy was absorbed by pulping liquors and hog fuel. Hog fuel achieved some noticeable gains in market share in 1977/1978 and 1982/1983. The natural gas and electricity shares remained fairly steady until 1984, when electricity's share increased significantly due to the appearance of boiler electricity demand in one of the four eastern pulp mills in the sample. This boiler power was the result of Hydro-Quebec's industrial boiler conversion program, and was used by the mill to reduce its reliance on residual fuel oil.

For the sample of eastern newsprint mills, the impact of the Hydro-Quebec program is much more pronounced (see Table 4.3). Ten Quebec mills accounted for about 11 petajoules of boiler electricity use between 1983 and 1984. Again, the increase in electricity's market share was at the expense of residual fuel oil. Unlike the kraft pulp mill sample, however, RFO's share remained relatively constant through 1982, while natural gas exhibited a general decline. The rebound in the natural gas share in 1984 reflects "hedging" behaviour on the part of industry to develop natural gas contracts in the face of uncertainty about future electricity prices and supply.

As discussed in Section 4.2, self-generated energy makes up a much smaller share of input energy requirements in newsprint mills than in kraft pulp mills. Nevertheless, in the sample of 19 newsprint mills, the use of hog fuel grew from a 6 percent share of total energy input in 1972 to a 16 percent share in 1984.

4.3.1 Base Case Results

The base case results of our analysis of energy intensity trends are shown in Tables 4.4 through 4.7 and Figures 4.6 through 4.9. For each of the product samples, indexes of energy intensity have been calculated by dividing an index of total energy use by a corresponding index of physical production. The tables report both Btu and Divisia quantity indexes of input energy. In addition, results are shown for four different specifications of energy demand:

- * purchased energy only--excluding self-generated fuel and electricity;
- * total energy--including self-generated fuel and electricity;
- * total energy minus spent pulping liquors; and
- * purchased energy plus hog fuel.

In all cases, the indexes have been computed relative to the CPPA survey base year of 1972. Preliminary analysis was conducted using 1976 as the base period, but was rejected because that was not a representative year for the Canadian pulp and paper industry. Specifically, the industry was recovering from a major work stoppage that saw total output fall by 24 percent in 1975.⁶

TABLE 4.4
INDEXES OF ENERGY USE
BLEACHED KRAFT PULP SAMPLE
BASE CASE BTU INDEX
(1972 = 100.0)

Year	Production		All Fuels ^a	
	000 tonnes	Index	Energy Index	Intensity Index
1972	2558.4	100.0	100.0	100.0
1976	2870.2	112.2	110.6	98.6
1977	2743.9	107.3	108.1	100.8
1978	3006.8	117.5	119.1	101.3
1979	2979.8	116.5	115.4	99.1
1980	3178.1	124.2	118.5	95.4
1981	2802.9	109.6	106.0	96.7
1982	2673.5	103.3	102.3	97.9
1983	2922.7	114.2	105.1	92.2
1984	2832.8	110.7	103.1	93.1

Year	Purchased Fuels ^b		All Fuels - Pulping Liquors	
	Energy Index	Intensity Index	Energy Index	Intensity Index
1972	100.0	100.0	100.0	100.0
1976	102.6	91.4	116.7	104.0
1977	91.0	84.9	109.3	102.0
1978	96.4	82.0	119.4	101.6
1979	98.6	84.6	117.7	101.1
1980	100.2	80.7	116.0	93.4
1981	89.0	81.2	102.1	93.2
1982	81.7	78.2	101.2	96.8
1983	74.8	65.3	102.3	89.6
1984	74.1	66.9	97.1	87.7

^aIncludes self-generated energy.

^bExcludes self-generated energy.

TABLE 4.5

INDEXES OF ENERGY USE
BLEACHED KRAFT PULP SAMPLE
BASE CASE DIVISIA INDEX
(1972 = 100.0)

Year	Purchased Fuels ^a			All Fuels - Pulping Liquors ^{b,c}		
	Production Index	Energy Index	Intensity Index	Energy Index	Intensity Index	Intensity Index
1972	100.0	100.0	100.0	100.0	100.0	100.0
1976	112.2	102.5	91.3	111.6	99.5	99.5
1977	107.3	91.5	85.3	100.8	94.0	94.0
1978	117.5	94.3	80.2	97.2	82.7	82.7
1979	116.5	108.5	93.2	107.9	98.9	98.9
1980	124.2	102.7	82.7	98.9	80.4	80.4
1981	109.6	90.0	82.1	88.0	81.6	81.6
1982	103.3	82.1	78.5	85.3	81.3	81.3
1983	114.2	83.6	73.2	92.9	85.4	85.4
1984	110.7	99.1	89.5	100.6	90.9	90.9

All Fuels

Year	80% Discount ^d			50% Discount ^e			20% Discount ^f		
	Energy Index	Intensity Index	Intensity Index	Energy Index	Intensity Index	Intensity Index	Energy Index	Intensity Index	Intensity Index
1972	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1976	107.6	95.9	91.5	109.3	97.5	97.5	110.3	98.3	98.3
1977	98.1	91.5	83.5	103.3	86.3	86.3	106.2	99.0	99.0
1978	98.2	83.5	82.4	102.9	87.6	87.6	105.5	89.8	89.8
1979	107.6	92.4	82.7	107.1	92.0	92.0	106.9	91.8	91.8
1980	100.9	81.2	82.9	100.0	80.5	80.5	99.5	80.1	80.1
1981	90.8	82.9	83.4	91.3	81.4	81.4	91.6	83.6	83.6
1982	84.1	80.5	79.3	85.4	81.8	81.8	86.1	82.4	82.4
1983	90.6	79.3	91.1	95.2	83.4	83.4	97.6	85.4	85.4
1984	100.9	91.1	102.2	102.2	92.3	92.3	102.9	92.9	92.9

^aExcludes self-generated energy.

^bIncludes self-generated energy.

^cBased on 50% pricing discount for waste fuels.

^dPrice discount assumed for waste fuels relative to fuel oil/natural gas.

TABLE 4.6
 INDEXES OF ENERGY USE
 INTEGRATED NEWSPRINT SAMPLE
 BASE CASE RTU INDEX
 (1972 = 100.0)

Year	Production		All Fuels ^a	
	000 tonnes	Index	Energy Index	Intensity Index
1972	4089.9	100.0	100.0	100.0
1976	3920.8	96.6	94.7	98.1
1977	4128.2	101.4	97.0	95.6
1978	4460.3	109.6	105.3	96.0
1979	4572.6	112.4	104.5	93.0
1980	4588.6	112.7	103.1	91.4
1981	4694.4	115.3	104.1	90.2
1982	4066.0	99.9	93.4	93.5
1983	4139.8	101.7	94.5	92.9
1984	4461.0	109.6	101.2	92.4

Year	Purchased Fuels ^b		Purchased + Hog Fuel	
	Energy Index	Intensity Index	Energy Index	Intensity Index
1972	100.0	100.0	100.0	100.0
1976	95.4	98.8	95.4	98.8
1977	95.1	93.8	96.0	94.6
1978	101.3	92.5	104.9	95.4
1979	98.1	87.3	102.3	91.2
1980	96.7	85.8	101.1	89.7
1981	96.8	83.9	102.7	89.1
1982	87.2	87.2	92.5	92.6
1983	84.7	83.3	92.7	91.2
1984	88.8	81.0	100.4	91.6

^aIncludes self-generated energy.

^bExcludes self-generated energy.

TABLE A.7

INDEXES OF ENERGY USE
INTEGRATED NEWSPRINT SAMPLE
BASE CASE DIVISION INDEX
(1972 = 100.0)

Year	Production Index	Purchased Fuels ^a		Purchased + Hog Fuels, c	
		Energy Index	Intensity Index	Energy Index	Intensity Index
1972	100.0	100.0	100.0	100.0	100.0
1976	96.6	100.4	103.9	100.4	104.0
1977	101.4	99.4	98.0	99.3	97.9
1978	109.6	105.9	96.7	107.2	97.8
1979	112.4	102.9	91.6	104.6	93.1
1980	112.7	95.3	84.5	95.5	84.7
1981	115.3	100.0	86.7	100.8	87.4
1982	99.9	90.9	91.0	91.0	91.1
1983	101.7	91.5	90.0	92.0	90.5
1984	109.6	111.3	101.5	113.8	103.8

Year	All Fuels ^b			
	80% Discount	50% Discount	20% Discount	
Year	Energy Index	Intensity Index	Energy Index	Intensity Index
1972	100.0	100.0	100.0	100.0
1976	97.8	101.3	99.3	102.8
1977	100.3	98.9	100.5	99.1
1978	108.8	99.2	109.0	99.4
1979	104.9	93.4	105.8	94.2
1980	97.9	86.9	97.3	86.3
1981	100.0	86.7	100.2	86.9
1982	90.7	90.8	90.9	91.0
1983	91.6	90.3	93.6	91.0
1984	111.1	101.4	113.0	103.1

^aExcludes self-generated energy.^bIncludes self-generated energy.^cBased on 50% pricing discount for waste fuels.^dPrice discount assumed for waste fuels relative to fuel oil/natural gas.

FIGURE 4.6
BLEACHED KRAFT PULP SAMPLE
BASE CASE BTU INDEXES

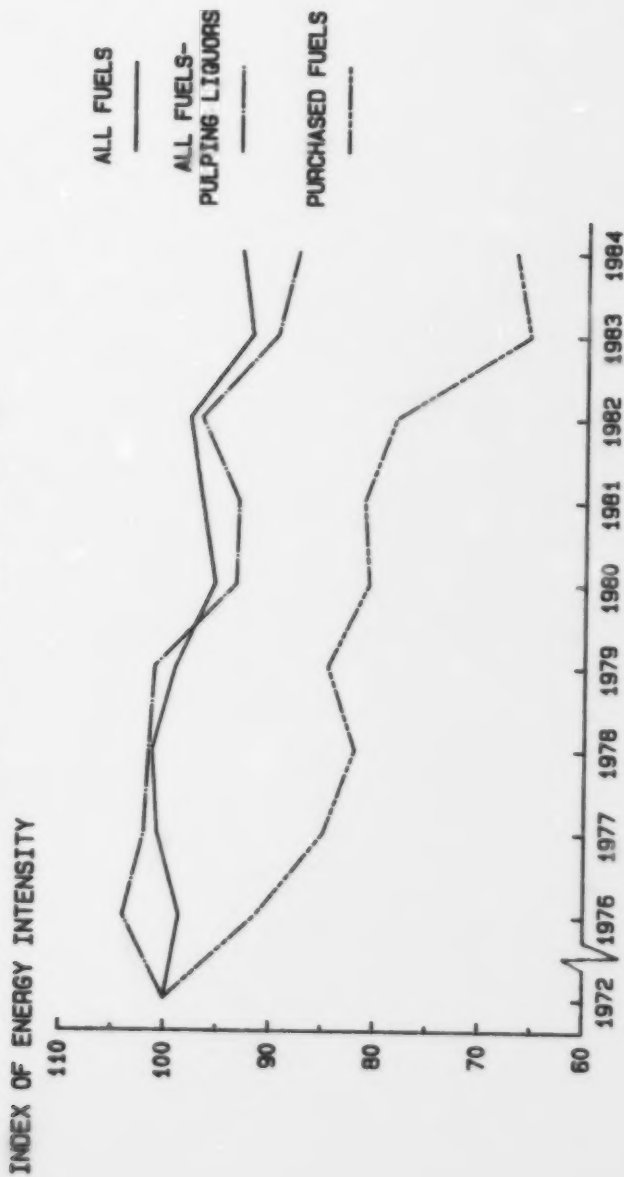
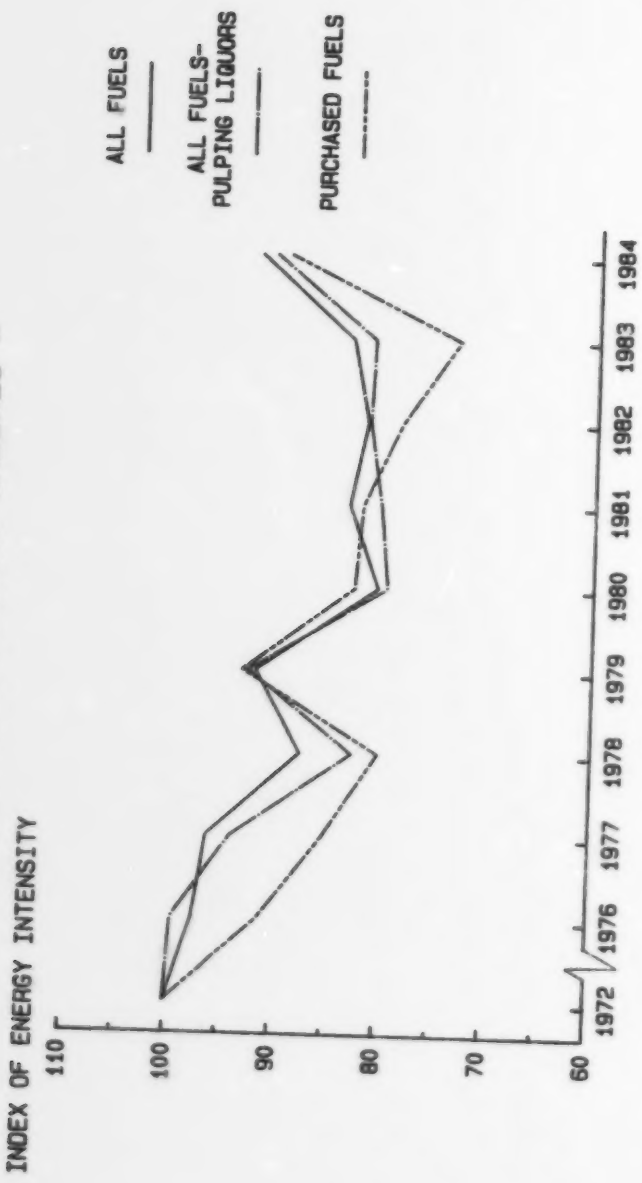


FIGURE 4.7
BLEACHED KRAFT PULP SAMPLE
BASE CASE DIVISIA INDEXES *



* Based on 50 percent pricing discount for waste fuels.

FIGURE 4.8
INTEGRATED NEWSPRINT SAMPLE
BASE CASE BTU INDEXES

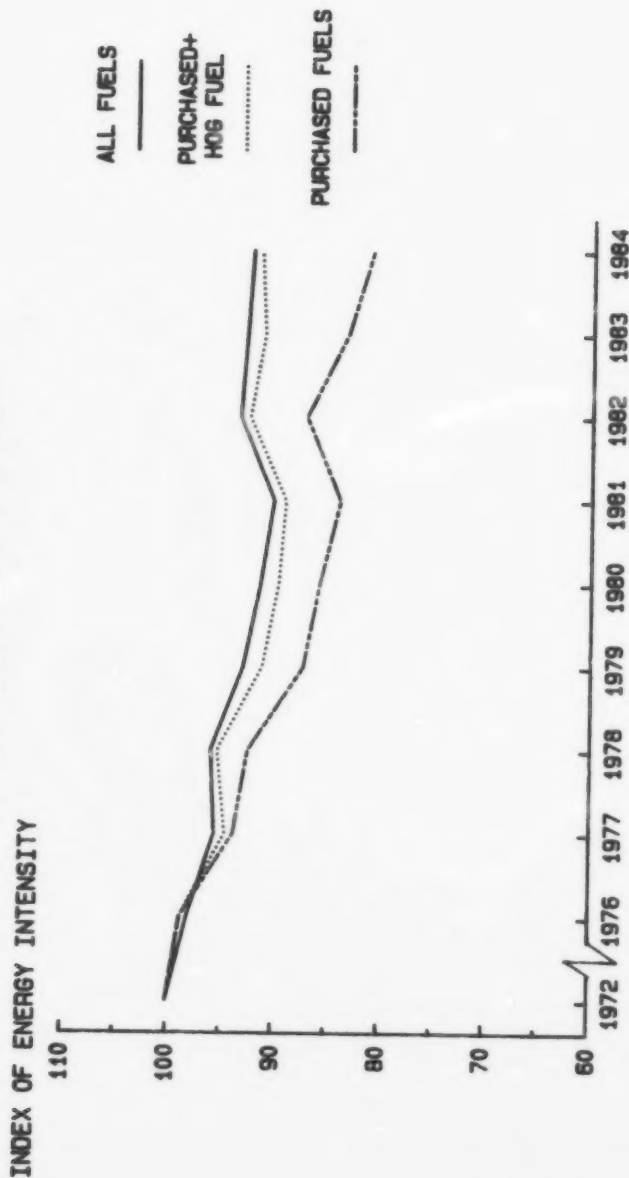
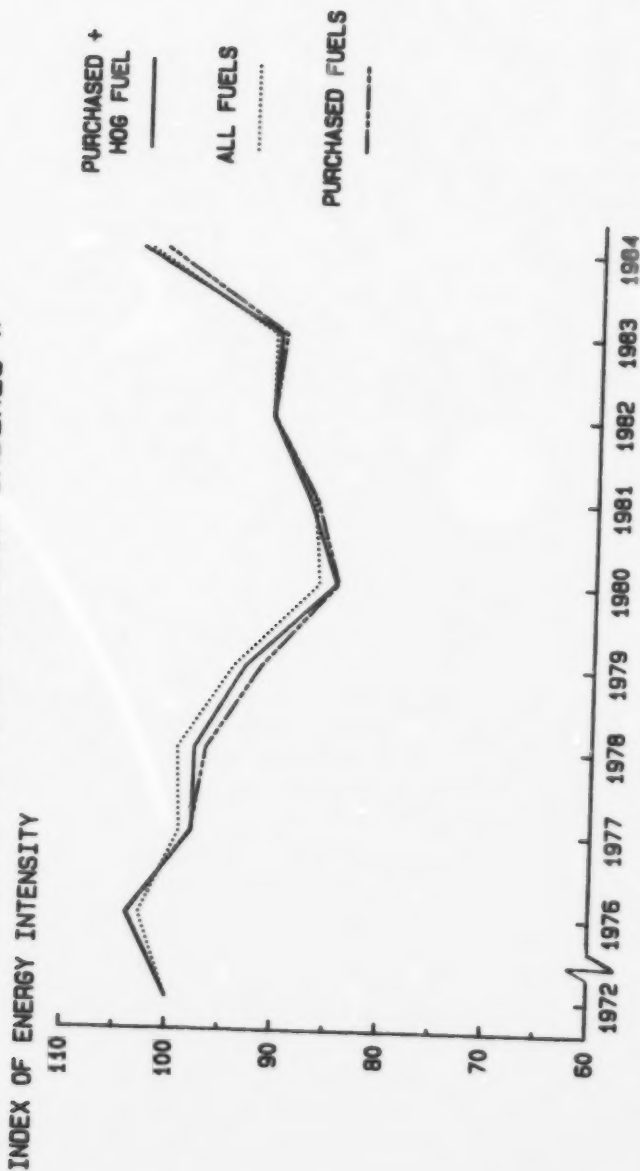


FIGURE 4.9
INTEGRATED NEWSPRINT SAMPLE
BASE CASE DIVISIA INDEXES *



* Based on a 50 percent pricing discount for waste fuels.

4.3.1.1 Kraft Mills

Over the 1976-1984 study period, the lowest production level for the sample of bleached kraft pulp mills occurred in 1982, during the economic recession (Table 4.4). Operating levels were also low in 1981, due to the beginning of the recession and a six-week labour dispute in the British Columbia sector of the industry.

Btu Indexes

In Table 4.4, the Btu index of purchased fuel and electricity indicates a 33 percent decline in energy intensity between 1972 and 1984. With a few exceptions, this decline was fairly continuous. The bump in the index in 1979 can be attributed to two of the larger western mills: one mill (Mill 12)⁷ reduced its total unit consumption of fuel, but consumed more fuel oil and less wood and process wastes; and the other (Mill 19) also increased its RFO use, but experienced a significant drop in production. Subsequently, the minor rise in 1981 reflects the impact of lower capacity utilization, that is, energy use fell less than proportionately to the decline in output. In 1982, on the other hand, purchased energy per tonne actually declined, despite the bottoming out of production. Finally, the slight increase in the index in 1984 is again the result of Mill 19 which consumed 20 percent more RFO and purchased electricity, while continuing to face reduced utilization rates.

In terms of individual mill trends, all of the sample, with the exception of 2 mills, demonstrated noticeable declines in purchased energy inputs. Three of these mills (Mills 1, 12 and 17), accounting for 18 percent of total 1984 output, showed intensity declines of between 35 and 75 percent by the end of the period.⁸

Turning to the Btu index for all fuels and electricity, there was a much smaller decline in energy use per tonne compared to the purchased fuels case. Moreover, the biggest reduction in intensity occurred in 1983 and was due, in large part, to improved production levels over which to spread the fixed costs of energy (the capacity utilization effect). In the sample of 15 mills, only 7 mills exhibited a continuous fall in energy intensity while the remainder showed little change, increases, or declines at the end of the period.

The pattern of total energy use per tonne reflects the substitution that has taken place between fuel oil and wood and process wastes. For example, the rise in the All Fuels Index in 1977/1978 corresponds to growth years for both hog fuel and spent pulping liquors. When process wastes are excluded from the analysis (All Fuels-Pulping Liquors), the intensity index is, of course, lowered on average over the period--particularly in the final years when pulping liquors made some gains in market share.⁹

Divisia Indexes

Relative to the Btu indexes, the Divisia indexes of energy intensity tend to be more volatile at the individual mill level. This is a result of two factors: (1) by weighting fuels according to expenditure shares, the Divisia quantity index is influenced directly by changes in energy prices, as well as by changes in the volumes of energy; and (2) the index is highly responsive to sharp movements in the quantities of individual fuel types.¹⁰ For the entire group of mills, an example of the impact of price fluctuations is given by the jump in the Divisia Purchased Energy Index in 1979, caused by an increase in residual fuel oil consumption (Table 4.5). In this case, the jump is even more pronounced than for the comparable Btu index since RFO is a higher-priced fuel and, furthermore, its price was rising faster than other energy prices in that year.

Typically, when looking at the Divisia and Btu indexes of energy intensity, there are some important differences to note. To begin with, the Divisia quantity index weights the contribution of each fuel type by its share of total energy expenditures, while the Btu index assigns weights according to each fuel type's share of total energy quantity. Therefore, the paths of the two indexes diverge according to differences in their weights, and according to the extent to which relative fuel prices reflect relative heat contents and combustion efficiencies.¹¹ Furthermore, the Btu indexes in Table 4.4 have not been adjusted for efficiency, whereas the Divisia indexes implicitly take account of relative efficiencies.¹² Given the substitution of lower efficiency wastes for higher efficiency purchased fuels, one would expect an efficiency-adjusted Btu index to show a greater decline in energy intensity than the unadjusted Btu index.

In spite of these differences, both the Divisia and Btu indexes show a similar downward trend in energy use per unit of output.

Comparatively speaking, the Divisia index tends to exhibit greater increases during years in which there was a rise in higher cost fuel consumption, and greater declines during years in which these fuels were being displaced. Indeed, the most significant declines in the All Fuels Divisia Index occur in 1978, 1980, and 1982 when pulping liquors and hog fuel were growing at the expense of residual fuel oil. The jump in this index in 1984 is attributable to increased use of electricity and fuel oil at two eastern and two western mills. Again, the increase is compounded by the price effect of moving to higher cost fuels (RFO and electricity).

The different pricing assumptions for wood and process wastes--20, 50 and 80 percent of the cost of alternative fuel at the mill (natural gas or residual fuel oil)--have a noticeable impact on the change in the All Fuels Index. That is, the greater the pricing discount assumed for hog fuel and pulping liquors, the lower the weights applied to their contributions to total energy and, hence, the greater the decline in the energy intensity index. Therefore, in Table 4.5 the three indexes for All Fuels tend to move in tandem downward, except in 1979/1980 when the relationship is reversed. The reason for this reversal is the 1979 shift in market share from wastes to residual fuel oil, which has a stronger impact on the index the greater the price differential between RFO and wastes.

On an individual plant basis, 10 of the 15 kraft pulp mills showed a significant decline in their Divisia All Fuels Indexes. In each case, gains in energy efficiency were achieved by reducing consumption of residual fuel oil or natural gas and increasing consumption of wastes. The remaining 5 mills in the sample were characterized by a generally flat trend in total energy use per output.

4.3.1.2 Newsprint Mills

Like the kraft pulp mill sample, the sample of 19 eastern integrated newsprint mills showed a substantial drop in output in 1982 (Table 4.6). However, in contrast to kraft pulp, 1981 was a record production year for the period, and the recovery in 1983 was much smaller.

Btu Indexes

In Table 4.6, the Btu index for purchased fuel and electricity indicates a continuous fall in energy intensity, with the exception of an upturn in 1982 ascribed to the capacity utilization effect discussed in Section 2.2.4. At the individual plant level, 15 mills reflected this downward trend in purchased energy use per tonne. In the remainder of the sample, 3 mills showed a flat trend and 1 mill (Mill 13) actually underwent an increase in intensity between 1976 and 1984 due to higher electricity consumption at the end of the period.

Relative to the kraft pulp sample, the newsprint sample exhibited a smaller decline in purchased energy use. To a certain extent, this was to be expected since purchased electricity is the principal energy type in newsprint production and electricity requirements tend to be fairly inflexible in the short term. Furthermore, wood and process wastes make up a much smaller share of total input energy than in kraft pulping. Nevertheless, there were significant savings in purchased energy over the period. Prior to 1982, most of these savings came out of natural gas and coal sources, with residual fuel oil's share of input energy having remained fairly stable. From 1982 on, the consumption of RFO dropped significantly.

When self-generated fuel and electricity are added into the index (All Fuels), the drop in energy intensity is less pronounced. This is due primarily to the doubling of hog fuel consumption between 1972 and 1984 (see Purchased Fuel + Hog Fuel) which was sufficient to affect the index despite its comparatively small share of total energy. For the All Fuels case, 11 of the sample mills demonstrated a decline in intensity, while 8 showed a flat or increasing trend. In the latter group, most mills were characterized by a rise in either hog fuel or electricity consumption. In the former group, 8 mills accounting for roughly 35 per cent of 1984 production showed significant declines in purchased energy--natural gas, RFO, electricity, or coal--which outweighed any attendant increase in hog fuel consumption.

Divisia Indexes

In comparison to the kraft pulp mills, there is a smaller difference between the Divisia and Btu indexes of energy intensity for

the integrated newsprint mills. The main reason would appear to be that the kraft pulping sample witnessed a stronger substitution between higher cost fuel oil and lower cost wastes over the historical period.

As shown in Table 4.7, the Divisia indexes are again more sensitive to changes in fuel prices and volumes than the comparable Btu indexes of Table 4.6. For example, the increase in the indexes in 1981 reflects the shift in market share out of less expensive coal and natural gas and into more expensive electricity. The most dramatic increase in the indexes, however, occurs in 1984. This jump is caused by the surge in boiler electricity demand at a number of mills, aimed at displacing residual fuel oil. In all cases, the Divisia indexes rebound above their 1972 level, despite the lower price of purchased electricity relative to fuel oil.

On a plant-by-plant basis, 4 mills showed a decline in energy intensity (All Fuels) over the entire 1976-1984 period, due mainly to the displacement of natural gas and RFU by cheaper wood wastes. Twelve mills exhibited a decline in energy intensity up to 1984, when the index jumped because of increased boiler electricity and/or hog fuel use. The remaining 4 mills in the sample demonstrated a flat trend in energy use per tonne of output.

4.3.2 Sensitivity Results

This section considers two "sensitivities" on the base case results reported above. In the first sensitivity case, the Btu indexes of energy intensity are adjusted to account for the combustion efficiencies of component fuels. In the second sensitivity case, boiler electricity demand is separated from motive electricity demand, in order to observe the effect of Hydro-Quebec's industrial boiler program and other factors accounting for a rise in electric power requirements.

4.3.2.1 Adjusting for Efficiency

The Btu energy indexes in Tables 4.4 and 4.6 do not incorporate adjustments to input energy requirements for the combustion efficiencies of different fuels. It is possible to apply an estimated boiler efficiency to each fuel type, so that the input energy data are converted to a steam-equivalent basis. The usual procedure is to apply aggregate efficiency values which are constant across regions and over time.

In fact, boiler efficiencies have been improving over time, and not necessarily at the same rate for all fuels. These efficiencies are particularly hard to evaluate in the case of waste by-products such as hog fuel, which varies in its moisture content, composition, etc. A proper assessment of boiler efficiencies would require mill-level analysis of the age distribution of the boiler equipment stock in each year.

For purposes of illustration, this study uses aggregate "order-of-magnitude" estimates of efficiency, as given by the following:

Electricity	97%
Natural Gas, RPPs ¹³ and Coal	85%
Spent Pulping Liquors	55%
Hog Fuel	65%

The estimated efficiencies for hog fuel and pulping liquors are considered to be fairly conservative, and have been adopted to minimize any bias towards wastes in the analysis of energy intensity.

Tables 4.8 and 4.9 and Figures 4.10 and 4.11 present the results of adjusting the kraft pulp and newsprint data to steam-equivalent energy units. As expected, the effect of this adjustment is to lower the Btu indexes, due to the displacement of higher efficiency purchased fuels by lower efficiency wastes over the 1976-1984 period.¹⁴ The reduction in the indexes is most significant in the case of the kraft pulp sample because of a stronger displacement effect. Moreover, the implication is that the Btu index will be lower, the greater the divergence in efficiency between wastes and conventional fuels.

4.3.2.2 Disaggregating Electricity Demand

Table 4.10 and Figure 4.12 show the results of separating out boiler and motive electricity demand for the newsprint mill sample. The kraft pulp sample has not been analyzed since only one of its 15 mills reported boiler electricity use during the historical period. In fact, the data on motive power may include some boiler applications prior to 1983, as the two have only been reported separately since that year.

TABLE 4.8
 INDEXES OF ENERGY INTENSITY
 BLEACHED KRAFT PULP SAMPLE
 EFFICIENCY-ADJUSTED BTU INDEX
 (1972 = 100.0)

Year	Production Index	All Fuels ^a		All Fuels - Pulping Liquors	
		Unadjusted Intensity Index	Adjusted Intensity Index	Unadjusted Intensity Index	Adjusted Intensity Index
1972	100.0	100.0	100.0	100.0	100.0
1976	12.2	98.6	98.5	104.0	102.1
1977	107.3	100.8	99.3	102.0	98.8
1978	117.5	101.3	99.4	101.6	96.0
1979	116.5	99.1	97.8	101.1	98.1
1980	124.2	95.4	93.8	93.4	91.1
1981	109.6	96.7	95.0	93.2	91.1
1982	103.3	97.9	95.9	96.8	93.4
1983	114.2	92.0	89.2	89.6	85.2
1984	110.7	93.1	90.3	97.1	84.2

^aIncludes self-generated energy.

TABLE 4.9

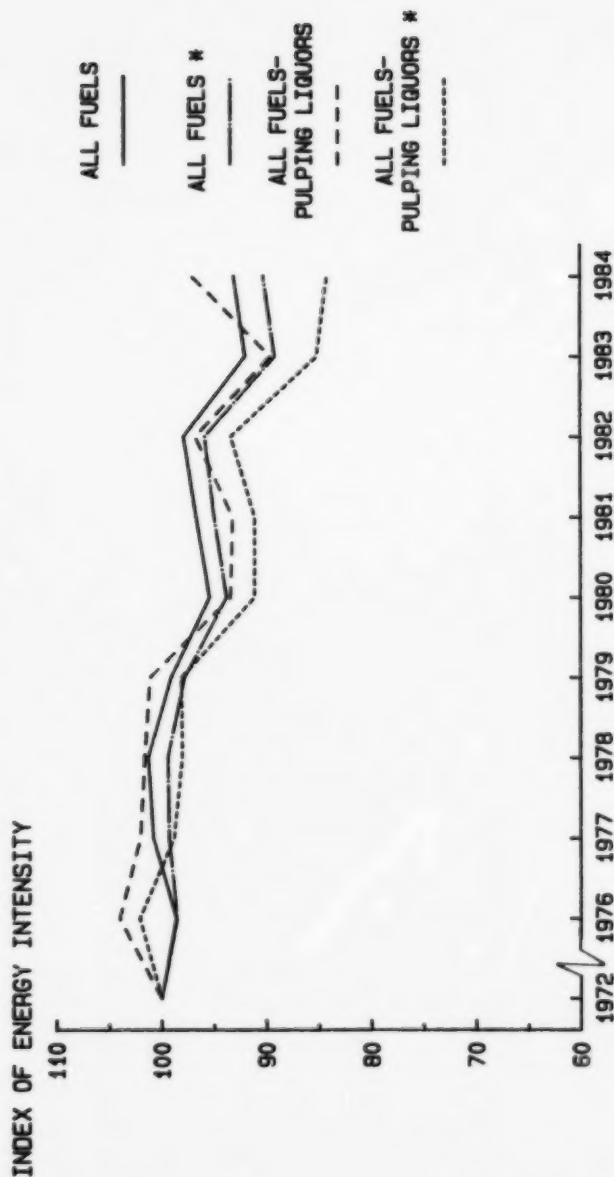
INDEXES OF ENERGY INTENSITY
INTEGRATED NEWSPRINT SAMPLE
EFFICIENCY-ADJUSTED BTU INDEX
(1972 = 100.0)

Year	Production Index	All Fuels ^a		Purchased + Hlog Fuel ^b	
		Unadjusted Intensity Index	Adjusted Intensity Index	Unadjusted Intensity Index	Adjusted Intensity Index
1972	100.0	100.0	100.0	100.0	100.0
1976	96.6	98.1	98.8	98.8	99.4
1977	101.4	95.6	96.3	94.6	95.3
1978	109.6	96.0	96.0	95.4	95.3
1979	112.4	93.0	92.7	91.2	90.8
1980	112.7	91.4	91.3	89.7	89.5
1981	115.3	90.2	90.1	89.1	88.7
1982	98.9	93.5	93.5	92.6	92.4
1983	101.7	92.9	92.4	91.2	90.7
1984	109.6	92.4	91.6	91.6	90.9

^aIncludes self-generated energy.

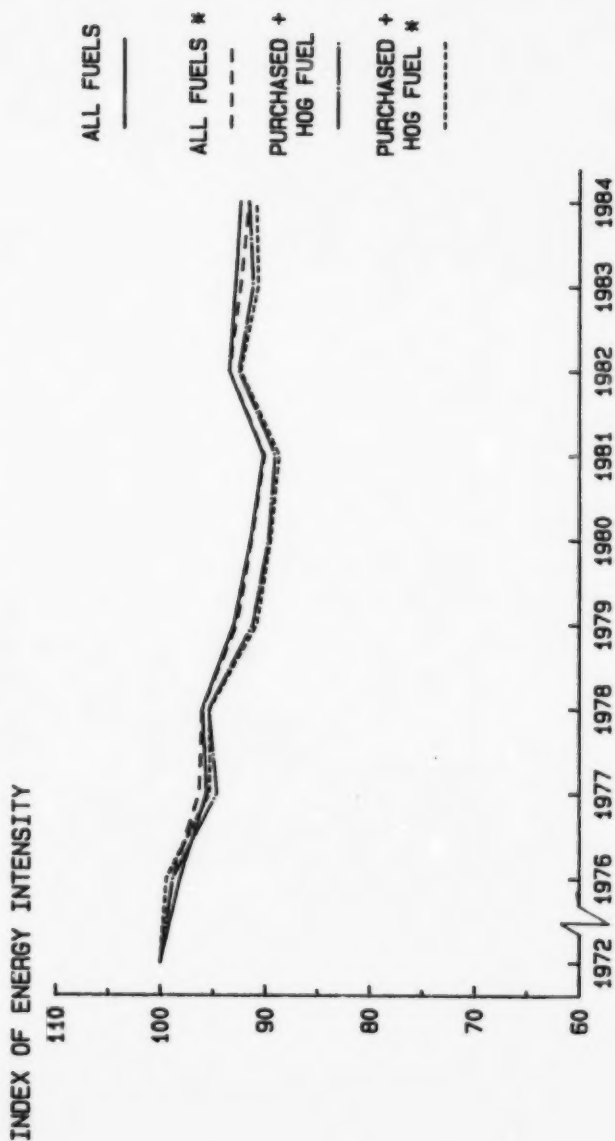
^bExcludes self-generated hydro power and pulping liquors.

FIGURE 4.10 BLEACHED KRAFT PULP SAMPLE -
EFFICIENCY ADJUSTED BTU INDEXES



* Adjusted for efficiency.

FIGURE 4.11 INTEGRATED NEWSPRINT SAMPLE -
EFFICIENCY ADJUSTED BTU INDEXES



* Adjusted for efficiency.

TABLE 4.10

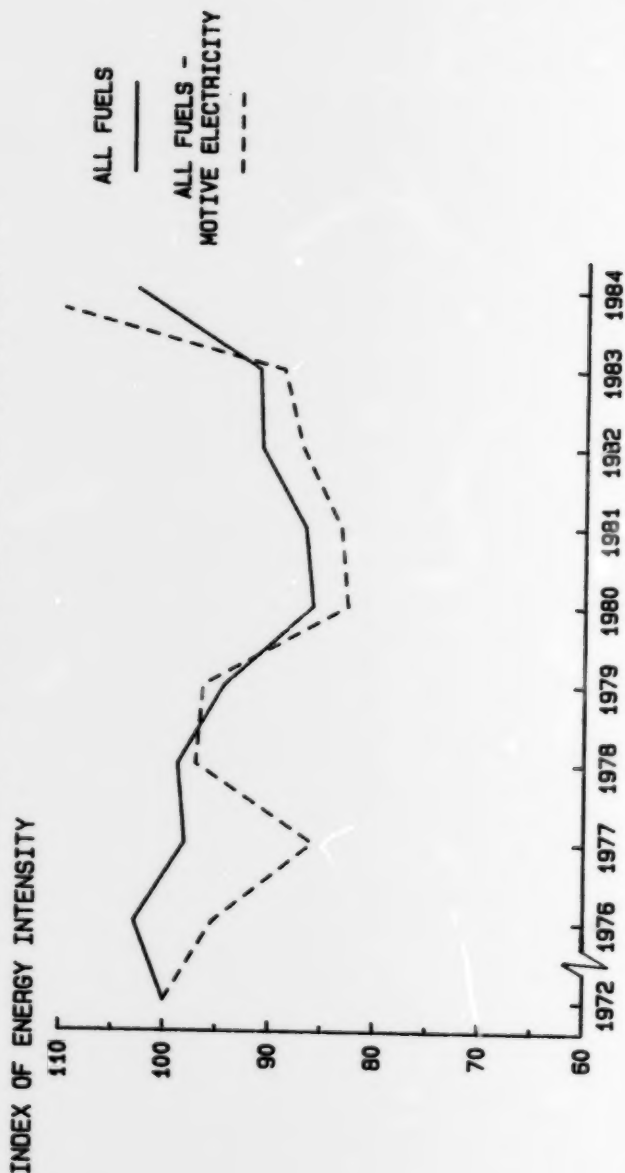
INDEXES OF ENERGY USE
 INTEGRATED NEWSPRINT SAMPLE
 DIVISIA INDEX ADJUSTED FOR
 BOILER VS. MOTIVE POWER^{a,b}
 (1972 = 100.0)

Year	Production Index	All Fuels Unadjusted Index	All Fuels - Motive Power	All Fuels - Boiler Power
1972	100.0	100.0	100.0	100.0
1976	96.6	102.9	95.4	102.9
1977	101.4	98.1	85.9	98.1
1978	109.6	96.8	97.1	98.8
1979	112.4	94.4	96.4	94.4
1980	112.7	86.0	82.7	86.0
1981	115.3	86.8	83.4	86.8
1982	99.9	91.0	87.1	91.0
1983	101.7	91.3	89.0	86.2
1984	109.6	103.0	117.1	84.4

^aExcludes 2 mills from base case sample of 19 mills.

^bBased on 50 percent pricing discount for waste fuels.

FIGURE 4.12 INTEGRATED NEWSPRINT SAMPLE -
SENSITIVITY ANALYSIS ON BOILER AND MOTIVE
ELECTRICITY DEMAND (DIVISIA INDEXES) *



* Two additional mills omitted from sample of 19 mills. Based on 50 percent pricing discount for wastes.

In the disaggregation of electricity demand, 2 mills (Mill 3 and Mill 5) have been dropped from the original sample of 19 mills. Aside from electric power, these mills relied solely on fuel oil as an energy source. When motive electricity (purchased and self-generated) was omitted from the analysis, the existence of switching between residual fuel oil and distillates generated sharp swings in the Divisia quantity index. Therefore, the indexes in Table 4.10 pertain to a smaller sample of 17 integrated newsprint mills.

The index excluding motive electric power is intended to demonstrate the impact of Hydro-Quebec's industrial discount program, which is currently drawing to a close. This program has paid for the capital cost of conversions to electric boilers. In addition, the utility has provided 4-year sales contracts discounting the price of purchased electricity relative to alternative fuels (natural gas or residual fuel oil).

By treating motive demand as a "captive market" for electricity the Divisia index can be defined in terms of the fuels that compete for boiler demand alone. The resulting index (All Fuels - Motive Power) is, generally lower than the All Fuels specification, except in 1984 when there was a sharp rise in boiler electricity consumption. When the boiler electricity component is excluded from the analysis (All Fuels - Boiler Power), the Divisia index falls below its 1983 level, as market share shifts to motive electricity.

The difference between the All Fuels and All Fuels - Motive Power indexes gives some indication of the contribution of motive electricity to total energy use over the period. Until the appearance of boiler electricity demand in 1983/1984, electricity showed some increase in intensity of use, relative to other fuels which experienced declines (see Table 4.11). For the pulp and paper industry as a whole, electric power requirements have grown in response to process changes such as the development of thermal mechanical pulping. In addition, certain conservation measures may result in an increase in electricity use in order to cut down on steam use: for example, the operation of fans and pumps for new heat recovery systems, greater press loading in paper machines to reduce drying requirements, and the replacement of steam turbine drives by electrical drives.¹⁵ Given data confidentiality, it is not known to what extent these factors are represented in the newsprint mill sample.

TABLE 4.11
 INTENSITY OF ENERGY USE
 INTEGRATED NEWSPRINT SAMPLE
 SELECTED FUELS AND TOTAL ENERGY
 (gigajoules per tonne)

	Motive Electricity ^a	Boiler Electricity	Natural Gas	Residual Fuel Oil	Total Energy ^b
1972	8.16	-	2.59	6.94	21.00
1976	8.94	-	3.17	5.36	20.60
1977	9.15	-	2.70	5.14	20.08
1978	8.69	-	2.79	5.07	20.17
1979	8.45	-	2.65	4.82	19.54
1980	8.49	-	2.47	4.86	19.20
1981	8.66	-	2.17	4.85	18.95
1982	9.07	-	2.13	5.15	19.64
1983	9.21	0.26	1.87	4.09	19.50
1984	7.86	2.18	2.17	2.91	19.40

^apurchased and self-generated electricity.

^bincludes self-generated energy.

4.3.3 Summary

This chapter has examined trends in energy intensity for two product groups in the Canadian pulp and paper industry. The main points of the analysis can be summarized as follows:

- Over the past decade there has been a substitution out of higher cost fuels, particularly residual fuel oil, into lower cost energy sources such as wood and process wastes.
- In addition to fuel substitution, there is evidence of overall energy conservation, that is, a declining trend in total input energy per unit of product.
- When energy inputs are adjusted for the efficiencies of different fuels, the decline in total energy intensity (using the Btu index) is even greater. This result follows from the lower efficiency of wastes relative to conventional purchased fuels.
- The data indicate that Hydro-Quebec's industrial discount program has had a significant impact on electricity demand.

In the next chapter, we compare our results to the CIPEC and EMR findings (Chapter 1) and outline some suggestions for further study.

Footnotes

¹T. N. McLenaghan, "Pulp and Paper Industry," Energy and Industrial Development in Canada: Proceedings of the Canadian National Energy Forum, Ottawa, November 1981.

²CIPEC Task Force Council, Canadian Industry Program for Energy Conservation: 1984 Report (Ottawa: Energy, Mines and Resources Canada, 1985), p. 58.

³Pulp and Paper Canada, Volume 76, No. 10, October 1975 and Volume 85, No. 3, March 1984. This magazine publishes an annual worldwide survey of TMP capacity.

⁴Canadian Pulp and Paper Association, 1985 Reference Tables (Montreal: CPPA, December 1985), p. 14.

⁵This 80 percent differential is based on the following estimates of unit electricity consumption: 2200 kw.h/tonne (oven-dry) for TMP and 1200 kw.h/tonne for stone groundwood. D. Baillard, C. Berger, A. Haurie, R. Loulou and H. I. Simonsen, Modelling Energy/Technology Choices in the Pulp and Paper Industry of Canada: The Markal Approach, Report Prepared for the Industrial Energy Division of Energy, Mines and Resources Canada (Montreal: GERARD, Ecole des Hautes Etudes Commerciales, July 1986) Appendix 1, Table A.1.1.

⁶Supra, footnote 4, p. 7.

⁷The identities of individual mills and companies have been kept confidential in the CPPA database. In the analysis here, mills have been arbitrarily numbered in order to observe any strong divergencies in individual mill energy use from the overall sample trends.

⁸For the 1976-1984 period (i.e., excluding 1972) the declines were between 20 and 40 percent in the case of these 3 mills.

⁹Note that the level of the index is actually increased prior to 1980 when pulping liquors are omitted. This is due to the fact that the share of pulping liquors in total energy was higher in 1972 than in the years 1976 through 1979 (see Table 4.2). After 1979, the pulping liquors' share exceeded its 1972 level and, therefore, the index is lowered relative to the All Fuels case.

¹⁰In particular, the Divisia quantity index encounters problems when individual fuel types appear or disappear from one year to the next.

¹¹For a comparison of the Divisia and Btu indexes see: Nguyen U. Hong, "Two Measures of Aggregate Energy Production Elasticities," The Energy Journal, Volume 4, Number 2, April 1983, pp. 172-177; and Jean-Thomas Bernard and Pierre Cauchon, "Why Thermal and Economic Measures of Energy Consumption Differ" (Quebec City: Department of Economics, University of Laval, February 1985).

¹²Basically, the Divisia quantity index is invariant with respect to efficiency, providing the relative efficiencies of the various fuels do not change over time. See Appendix A for more detail.

¹³Refined petroleum products (RPPs) consist of residual fuel oil, distillates and LPGs. The order-of-magnitude efficiencies were obtained through contact with the Canadian Pulp and Paper Association in Montreal.

¹⁴Note that the newsprint indexes end up higher in 1976 and 1977 after the efficiency adjustment. This is the result of some declines in natural gas, RFO and coal use (85% efficiency) and an increase in electricity use (97% efficiency) during the early years. See Table 4.3.

¹⁵CIPEC Task Force Council, Canadian Industry Program for Energy Conservation: 1981 Report (Ottawa: Energy, Mines and Resources Canada, 1982), p. 63; and Adam Kahane, Industrial Electrification: Case Studies of Four Industries; Steel, Paper, Cement and Motor Vehicles Production in the United States, Japan and France, Research Report for the Electric Power Research Institute, RP-2345-42-00 (Berkeley: Lawrence Berkeley Laboratory, University of California, March 1986), p. 32.

Chapter 5

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The purpose of this study has been to contribute to the discussion on industrial energy demand in Canada by examining one relatively energy-intensive industry: pulp and paper production. In Chapter 4, a mill-specific database from the Canadian Pulp and Paper Association (CPPA) was used to compute historical energy intensities for samples of newsprint and kraft pulp mills. These intensities were then tracked over the 1976-1984 study period, in order to observe any trends in improved efficiency of energy use.

In the analysis, energy intensity was defined as an index of energy inputs divided by an index of physical production. Two types of energy index were specified: (1) a Btu index aggregating all fuel types according to their energy or heat contents; and (2) a Divisia quantity index weighting the contribution of each fuel type by its share of total energy expenditures. The Divisia index of energy intensity tended to be more erratic because of the influence of relative prices on the expenditure weights, and because the quantity index is highly sensitive to sharp increases in the consumption of individual fuels. Furthermore, the results of the Divisia analysis are qualified by the lack of good (mill-specific) costing data for purchased and self-generated fuel and electricity. Nevertheless, both the Btu and Divisia intensity indexes show evidence of two trends in kraft pulp and newsprint production: (1) a shift from higher cost residual fuel oil to lower cost energy types such as combustible wastes; and (2) a decline in total energy use per tonne (energy conservation).

For the purposes of sensitivity analysis, the Btu indexes of energy use were adjusted to a steam-equivalent basis, to reflect the different combustion efficiencies of the component fuels. The effect of adjusting for efficiency was to generate a greater decline in intensity because of the displacement of higher efficiency purchased fuels by lower efficiency wastes over the historical period. Clearly, the choice of combustion efficiencies will have an impact on the measurement of trends in energy use. The aggregate efficiencies used in this

study were fairly conservative and were intended to minimize any bias towards wastes in the analysis of energy intensity changes.

In the rest of this chapter, the results of the newsprint/kraft pulp analysis are compared with the findings of the CIPEC and EMR reports discussed in Chapter 1. Also, we draw some general conclusions with regard to analyzing industrial energy demand, and provide some suggestions for further work in the area.

5.1 Comparison to CIPEC and EMR Results

The energy intensity trends from Chapter 4 (CERI analysis) can be compared to the CIPEC and Halliwell and Valade (1984) results for pulp and paper energy use.¹ In the case of purchased fuel and electricity, all three sets of results indicate a clear decline in energy use per output. A major factor contributing to this decline was the displacement of purchased energy (e.g., RFO) by self-generated energy sources (wood and process wastes) over the historical period.

In the case of total fuels and electricity, however, the results differ. Table 5.1 presents a comparison of the CERI analysis for kraft pulp and newsprint mills, and the Halliwell and Valade analysis based on data from the Quarterly Report on Energy Supply-Demand in Canada (QRES).² For purposes of comparison, the CERI indexes of energy use have been converted to a common 1978 base year.

As shown in the table, the QRES data for purchased fuels and renewables yield a flat or slightly upward trend in energy intensity between 1978 and 1984. This trend reflects the rapid growth in consumption of wood and process wastes and the accompanying displacement of purchased fuels. Conceivably, the rise in energy intensity could be eliminated by adjusting for the lower efficiency of wastes relative to purchased fuels.

In contrast to the QRES results, the CERI indexes for newsprint and kraft pulp mills both indicate a decline in total energy use per tonne, even without any adjustment for relative efficiencies. Interestingly enough, the RDP index is not dramatically different from the index of physical production, at least in the case of kraft pulp mills. It would appear that there are differences between the basic CPPA and QRES energy data which are difficult to reconcile at this time.

TABLE 5.1
INDEXES OF ENERGY USE
QRESID VS. CERI ANALYSIS
ALL FUELS BTU INDEX
(1978 = 100.0)

QRESID Analysis				
Year	Output		Energy Use	
	RDP ^a (1971 \$M)	RDP Index	Energy Index	Intensity Index
1978	1435.9	100.0	100.0	100.0
1979	1424.3	99.2	101.4	102.2
1980	1436.5	100.0	105.3	105.3
1981	1393.1	97.0	99.2	102.2
1982	1253.6	87.3	98.6	112.9
1983	1392.1	96.9	102.9	106.1
1984	1401.4	97.6	97.6	100.0

CERI Analysis				
Year	Kraft Pulp Mills		Newsprint Mills	
	Production Index	Energy Index	Production Index	Intensity Index
1978	100.0	100.0	100.0	100.0
1979	99.1	96.9	97.8	96.9
1980	105.7	99.5	102.5	95.2
1981	93.2	89.0	105.2	98.9
1982	88.9	85.9	91.2	88.7
1983	97.2	88.3	92.8	89.7
1984	94.2	86.5	100.0	96.2

SOURCE: ENR Industrial Energy Study Database (October 1984), and Tables 4.4 and 4.6.

^aReal Domestic Product for Pulp and Paper Mills.

5.2 Principles for Analyzing Industrial Energy Demand

A number of general principles can be extracted from the examination of energy use in the Canadian pulp and paper industry. These principles demonstrate the complexity of analyzing energy demand in any given sector.

5.2.1 Disaggregation by Industry

Analysis of pulp and paper production demonstrates the importance of investigating energy use profiles on an individual industry basis. Pulp and paper provides a specific example of an industry in which lower cost, renewable energy forms have been substituted for higher cost, purchased energy. It has been estimated by industry representatives that roughly one-half of the efficiency gains to date were associated with "off-oil measures," while the other half were the result of housekeeping activities to reduce total energy use per unit of output.³ The potential for future gains may be restricted to adopting new processes and technologies which, in turn, is constrained by the availability of capital to individual companies.

Typically, the trends in energy intensity will vary across industries with such factors as the starting level of energy efficiency, the degree of conservation potential (the relative significance of housekeeping measures, availability of self-generated energy, etc.), technological developments, and financial capability. Therefore, a study of energy demand for the industrial sector as a whole must consider industry-specific trends in energy consumption and shifts in the composition of total industrial output across sectors.

5.2.2 Defining Energy Intensity

The results for the change in energy demand can depend to a large extent on how energy quantities are defined, e.g., purchased versus total fuel and electricity, or input versus output energy. In industries like pulp and paper, where higher efficiency energy sources have been displaced by lower efficiency energy sources, the measurement of input-energy units may indicate a rise in total energy intensity through time.

Moreover, quantity of energy use may not be the appropriate indicator for assessing improvements in energy efficiency. Of key importance to the industry producer is the change in his total costs of production over time. In the case of energy inputs into the production process, cost savings can result from the reduction of unit-energy consumption (e.g., through housekeeping measures) or from the substitution of lower cost for higher cost fuels. Therefore, from an industry perspective, the more relevant indicator of changing energy efficiency is energy's share of total production costs.

5.2.3 Other Production Inputs

An analysis of the pattern of energy demand should take account of other production inputs such as labour and non-energy materials. Overall production efficiency is a function of how all inputs interact to create output. Even where energy accounts for a significant share of total expenditures, it may be more efficient to increase energy consumption in order to economize on, say, raw materials. An example in pulp and paper production is given by the thermal mechanical pulping process which produces higher yields and saves on raw material costs, but requires almost twice as much electricity as conventional mechanical pulping methods.

In general, energy efficiency may be weighed against a number of corporate objectives including overall cost minimization and environmental control.

5.2.4 Energy-Using Processes

For a given industry, there may be significant variation in energy intensity at the product or process level. In this study, the two product groups--bleached kraft market pulp and newsprint with integral sulphite pulp--exhibited very different energy-using characteristics with respect to the distribution of purchased and self-generated fuels, degree of electricity-intensiveness, and contribution of waste by-products. Consequently, an analysis of energy demand for a particular industry should take account of shifts in the product mix and trends in the use of different production processes.

5.2.5 Regional and Plant-Specific Trends

Another source of variation in energy demand occurs at the regional and plant levels. The indexes of energy intensity in Chapter 4 showed some major differences across pulp and paper mills in terms of the ability to reduce unit-energy requirements and to substitute out of high cost fuels. Generally speaking, plants differ according to their accessibility, the cost and availability of fuels, vintage of the equipment stock, management skills, and various other factors. Thus, a particular plant may be modern and efficient, with new equipment and a strong energy management program, and its conservation potential will be smaller than that of an older or otherwise less energy-efficient facility.

This study did not investigate the regional patterns of energy demand in pulp and paper production. However, the mill-specific database used in Chapter 4 did suggest differences in energy consumption between eastern and western mills. For example, in the case of kraft pulp, wood wastes made up a larger share of total input energy for western (British Columbia) mills than for eastern mills.⁴ This can be attributed to the highly integrated nature of the B.C. industry, in which lumber (sawmill) and pulp mill operations are often combined. In view of these kinds of differences, an examination of energy intensity trends could be conducted on a regional level to assess the impact of varying fuel costs, resource availability, climate, etc.

5.2.6 End-Use Detail

Changes in energy demand are largely a function of the emergence and decline of specific end uses, and the way in which these end uses favour one fuel type over another. As an example, the general increase in electricity intensity of pulp and paper production reflects developments in two distinct end uses: (1) boiler electricity power, as a result of Hydro-Quebec's industrial discount program; and (2) motive electricity, due to various factors such as pollution control requirements, thermal mechanical pulping, and steam conservation measures. Consequently, an analysis of industry energy use should delve beneath the trends in different energy types to investigate the fuel-using potential of particular end uses.

5.3 Suggestions for Further Work

This study has pointed to a number of areas where further research on industrial energy demand could be performed, not only for the pulp and paper industry but for other sectors as well. Suggestions for further work can be classified according to "macro-level analysis" and "micro-level analysis."

5.3.1 Macro-Level Analysis

Although this study was based on plant-specific energy data, the analysis of energy-intensity trends was conducted at a more aggregated level, for samples of two product types. Several refinements could be made to the macro-level analysis, as noted below.

5.3.1.1 New Processes and Technologies

The pattern of energy consumption in industry is influenced by the continual introduction and development of new production processes and technologies. On an aggregate level, it would be useful to analyze: (1) the impact of technological progress and process changes such as the TMP process in pulp and paper,⁵ and (2) the effect of changes in the energy-using equipment stock. This second refinement to the analysis could allow one to assess the responsiveness of the equipment stock to changing energy prices. Unfortunately, in Canada there is no aggregate information available on additions to the capital stock and, therefore, extensive data gathering (i.e., a survey) would be required.

5.3.1.2 Capacity Utilization

Another important influence on the trend in energy intensity relates to movements in the level of capacity utilization. Analysis of this issue could examine the share of overhead (fixed) energy in total energy requirements, and the impact on energy use of disruptions in the production level due to strikes, reduced product demand, etc.

5.3.1.3 Utilization Efficiencies

In the sensitivity analyses contained in this study, rough "order-of-magnitude" estimates of boiler efficiencies were used to adjust the quantities of all fuel types to a steam-equivalent basis.

The efficiencies were assumed to be constant across regions and time periods. A more refined analysis of efficiency-adjusted energy use would attempt to address the relative changes that have taken place in the efficiencies of different fuels.

5.3.1.4 Cogeneration

As described in Chapter 3, the energy database in this study did not take account of transformations within the plant from one energy type to another. Thus, the data did not allow for any measurement of cogenerated electricity, a major energy source in pulp and paper production. In order to analyze the trend in output energy (i.e., after combustion and conversion losses), as opposed to input energy use, it would be necessary to estimate the proportion of each fuel type used in the cogeneration process.

5.3.1.5 Substitution Between Energy and Other Production Inputs

A final area for macro-level analysis concerns the interaction between energy and other inputs into the production process--labour, equipment, and non-energy materials. One approach to analyzing this issue would be to estimate historical production and costing relationships which link the various inputs in creating output ("production functions" and "cost functions").⁶ The estimated relationships could then be used to evaluate the impact of a rise in the price of each input on the demand for energy.

5.3.2 Micro-Level Analysis

As an alternative to aggregate analysis, trends in energy use could be investigated at the plant level, that is, through a case study approach. For the particular plant(s), this would involve a detailed examination of energy consumption patterns and the various factors outlined above: fuel prices and availability from year to year, the costs and quantities of materials and labour, investment in energy-saving equipment, changes in process or product mix, utilization rates, and so on. The advantage of such an analysis is that it would attempt to untangle the various offsetting influences on energy demand. The main disadvantage would lie in the generalization of individual mill trends to the industry as a whole.

Footnotes

¹See Chapter 1 for a discussion of the results of these two analyses: CIPEC Task Force Council, Canadian Industry Program for Energy Conservation, various annual reports (Ottawa: Energy Mines and Resources Canada); and Cliff Halliwell and Andre Valade, Industry Energy Demand: A Review of Recent Trends (Ottawa: Market Analysis and Statistics Division, Energy, Mines and Resources Canada, 1984).

²Statistics Canada Catalogue 57-003.

³Information obtained through contact with the Canadian Pulp and Paper Association.

⁴The original CPPA sample of bleached kraft pulp mills consisted of 14 western mills and 11 eastern mills. After omissions for incomplete data, the CERI sub-sample was left with 11 western and 4 eastern mills. Because of this small representation of eastern mills, it was not reasonable to analyze the western and eastern regions separately.

⁵See for example Adam Kahane, Industrial Electrification: Case Studies of Four Industries; Steel, Paper, Cement and Motor Vehicles Production in the United States, Japan and France, Research Report for the Electric Power Research Institute, RP-2345-42-00 (Berkeley: Lawrence Berkeley Laboratory, University of California, March 1986).

⁶For an example of this type of analysis see DataMetrics Limited, An Investigation of the Relationship between Energy and Other Production Inputs in Canadian Manufacturing, Report Prepared for the Energy Conservation and Oil Substitution Branch of Energy, Mines and Resources Canada, Industry Series No. 12 (Ottawa: Industrial Energy Division, January 1983).

APPENDIX A

THE DIVISIA QUANTITY INDEX
OF ENERGY CONSUMPTION

Appendix A

THE DIVISIA QUANTITY INDEX OF ENERGY CONSUMPTION

This appendix provides a description of the Divisia quantity index used for evaluating the change in energy consumption in the pulp and paper industry.

A.1 The Divisia Index Versus Thermal Conversion Factors

There is a considerable literature¹ on the problems of constructing an appropriate index of aggregate energy consumption. A common approach is to apply thermal conversion factors which express the component energy sources on a Btu-equivalent (or joule-equivalent) basis. The alternative is to adopt an economic approach whereby the energy types are weighted using their relative prices per unit of consumption.

The difficulty with a Btu-equivalent aggregation is that end-users of energy do not make their decisions in terms of heat content alone. Other characteristics, such as cleanliness, safety, ease of storage, the relative costs of end-use technologies, etc., enter the valuation of fuels in different applications. Furthermore, there are some end uses in which energy types are not easily substituted, given the existing equipment stock and technological constraints. To the extent that relative prices capture characteristics such as convenience and cleanliness, an economic price-weighted index of energy consumption is preferable to the common Btu approach.²

Of the various types of economic indexes in use, the Divisia index has a number of theoretical and computational advantages. Like other price-weighted indexes, it is grounded in the economic theory of the firm, according to which producers act to minimize costs by equating the relative productivity of energy and other inputs into the production process with their relative prices. Unlike current (Paasche) price-weighted indexes which assume perfect substitution between energy types, or base-weighted (Laspeyres) indexes which assume no substitution, the Divisia index allows for variable substitution

between inputs without imposing a priori constraints on the degree of substitution.³

The Tornquist (discrete) approximation to the Divisia index of energy consumption is defined as follows. The percentage change in aggregate energy consumption is a weighted average of the percentage changes of all energy types, where the weights take the form of mean expenditure shares:

$$\ln (E_t^* / E_{t-1}^*) = \sum_i w_{it} \ln (E_{it} / E_{i,t-1}) \quad (A.1)$$

where w_{it} is the arithmetic mean of the i^{th} energy type expenditure (price times quantity) share in periods t and $t-1$,

$$w_{it} = 0.5 * (w_{it} + w_{i,t-1}), \text{ and}$$

$$w_{it} = (P_{E_t} * E_{it}) / \sum_i P_{E_t} * E_{it}$$

The energy index can be computed either directly using this formula or indirectly using total energy expenditures divided by a discrete Divisia price index.

A.2 Input Versus Output Energy

One of the issues related to aggregating energy types is the choice of input versus output energy measurement.⁴ Input thermal units measure energy at the point at which it enters the energy-using system, whereas output thermal units measure the energy available for a given end use. It is output or available energy which is important to energy users in making their fuel choice decisions.

Using the Btu-equivalent approach, a preferable method of calculating aggregate energy consumption involves adjusting input thermal units for the efficiencies of the different energy types. The problem with such an approach is that, in order to be accurate, it

requires detailed information on efficiencies at the end-use level. Typically, studies adopting this method are based on aggregate efficiency coefficients which are assumed to be constant over time and across regions. By assuming constant efficiencies through time, one is circumventing the increase in efficiency which occurs in response to higher energy prices.

Given the assumption of a constant efficiency factor for each fuel, the discrete Divisia quantity index can be demonstrated to be invariant with respect to the choice of input or output energy measures. Adjusting both prices and quantities for efficiencies (e_i), the index becomes:

$$\ln (\bar{E}_t / \bar{E}_{t-1}) = \sum_i 0.5 * (\bar{w}_{it} + \bar{w}_{i,t-1}) \ln (E_{it} e_{it} / E_{i,t-1} e_{i,t-1}) \quad (A.2)$$

and

$$\bar{w}_{i,t} = \frac{\frac{P_{it}}{e_{it}} E_{it} e_{it}}{\sum_i \frac{P_{it}}{e_{it}} E_{it} e_{it}} = \frac{P_{it} E_{it}}{\sum_i P_{it} E_{it}} = w_{it}.$$

Further,

$$\ln (E_{it} e_{it} / E_{i,t-1} e_{i,t-1}) = \ln \frac{E_{it}}{E_{i,t-1}} * \frac{e_{i,t-1}}{e_{it}}$$

Substituting these two results into (A.2) and assuming that efficiencies do not change from year to year ($e_{it} = e_{i,t-1}$) reduces the efficiency adjusted index to the unadjusted index; that is, they are the same.

In practice, the error that results from the assumption of constant efficiency through time will depend on a number of factors: the time period over which energy use is analyzed, the degree of efficiency improvement and the extent to which it affects certain energy types over others, the importance of those energy types in total energy expenditures, etc.

In sum, the discrete Divisia index offers several advantages over an approach which uses thermal conversion factors to equate energy use on a Btu basis. While the discrete Divisia index is easier to compute than other general price-weighted indexes, it still requires information on the cost shares of all component energy types. This can present a problem in particular, for non-purchased fuels such as own-generation of hydroelectricity and wood and process wastes (see Appendix B.).

Footnotes

¹See for example R. Turvey and A. R. Nobay, "On Measuring Energy Consumption," Economic Journal, Volume 75, pp. 787-793; and Ernst R. Berndt, "Aggregate Energy, Efficiency, and Productivity Measurement," Annual Review of Energy, Volume 3, 1978, pp. 225-273.

²According to economic theory, in a world of perfectly competitive markets the prices of different energy types reflect the true costs of the resources which go into their production. In practice, however, actual relative prices will differ from marginal costs due to the presence of market imperfections (e.g., government regulation).

³For a discussion of the properties of the Divisia index see W. Erwin Diewert, "Exact and Superlative Index Numbers," Journal of Econometrics, Volume 4, May 1976, pp. 115-146. The Divisia has been shown to be an "exact" index, meaning that it retrieves the original value of the aggregator function.

⁴For a comparison of the effects of using input and output measures in modelling energy demand, see E. R. Berndt and G. C. Watkins, "Modelling Energy Demand: The Choice Between Input and Output Energy Measurement," Paper Presented to the Third IAEE World Conference, Cambridge, U.K., June 1982.

APPENDIX B

THE PRICING OF NON-PURCHASED FUELS

Appendix B

THE PRICING OF NON-PURCHASED FUELS

As described in the previous appendix, the calculation of a Divisia quantity index of energy consumption requires a total cost for each of the energy types consumed. In the case of purchased fuels, it is possible to obtain historical price series which indicate the market value of these fuels, and to compute energy expenditures as the product of price times quantity for each fuel.¹ However, it is more difficult to determine a cost for non-purchased fuels which may not have an observable, clearly-defined market. In the context of pulp and paper mills, self-generated hydroelectricity,² hog fuel, and spent pulping liquors are all non-purchased or self-generated fuels.

Conceivably, non-purchased fuels can be "valued" in several ways. First, price can be tied to the actual cost of obtaining the fuel, i.e., the costs of gathering, handling, processing, pollution control, waste disposal, etc. Second, an estimate can be made of the revenue which could be generated by "selling" the non-purchased fuel in some form of market. Third, price can be based on the cost avoided by not having to purchase fuel, i.e., the value of the least cost alternative fuel which would have to be consumed in its place.

B.1 Self-Generated Hydroelectric Power

For self-generated hydroelectricity, the first pricing method would involve calculating the cost of generation, composed of the operation and maintenance expenses of generation facilities, as well as a share of their capital costs. Presumably, this cost would be less than the price of purchased electricity. If not, the mill would have no incentive to install and run its own generating capacity.

The second pricing method would value self-generated power at the unit revenue that could be obtained by selling the power to other buyers. Assuming that the mill was linked to the provincial electric grid (as are all the plants in this study), this would entail sales of electricity to the major utility. Thus, the appropriate price for own-generation would be the utility "buyback rate."

Finally, the price of self-generated hydro can be related to the avoided cost of the marginal source of energy (the third pricing method). Since all of the sample mills analyzed here purchase some electricity, this marginal source is deemed to be additional purchases of electricity. Therefore, in the absence of data on own-generation cost and buyback rates, self-generated power is valued at the price of purchased electricity.

3.2 Wood and Process Wastes

The case of combustible wastes, hog fuel and spent pulping liquors is more complicated. Hog fuel and spent pulping liquors are by-products in the pulp and paper industry. Pulping liquors, in particular, are an integral part of the production process, specifically the recovery of pulping chemicals, and the amount of recovered pulping liquor tends to vary directly with the level of output. Hog fuel is a waste product produced on site in the initial debarking and chipping operations (or it may come from a nearby sawmill operation) which, if not used, must be disposed of. It may consist of bark, sawdust, shavings, trim ends, culls and butts. The development of hog fuel as an energy form has grown substantially since the early 1970s, due largely to the escalation in conventional fuel prices.

It is possible to value wood wastes on the basis of the least cost alternative purchased fuel. In doing so, adjustments should be made for differences in heat value, and in utilization efficiency if output energy units are being measured. In addition, there are other characteristics of fuels aside from thermal content which must be considered, e.g., ease of handling, reliability of supply, storage requirements, and environmental impact (see Appendix A). Thus, even if hog fuel were to have the same thermal content as, say, natural gas, the mill would probably still choose to use natural gas for reasons of superior non-energy characteristics. The implication is that when valuing wood waste in terms of "avoided cost," there should be a discount applied to the price of the least cost alternative fuel.

In addition to avoided cost pricing, the value of hog fuel can be determined using the actual cost of burning wood wastes. This would include the labour and equipment costs of gathering and transporting the wastes, operation of the boilers, factors for the capital cost of the hog-burning equipment including pollution control devices, etc.

For completeness, the cost of burning hog fuel should be offset by any savings that result from not having to dispose of the waste.

Finally, hog fuel can be valued at the price for which it could be sold in the market. Some of the mills studied here do report purchased hog fuel in a few years, although the database does not include any cost information. In terms of alternative uses, sawmill wastes can be used in pulp and paper-manufacture.

Historical data are not available at the mill level regarding either the actual costs of burning wood wastes or the purchase price of hog fuel sold. As a result, the avoided cost specification is adopted for the purposes of this study. Both hog fuel and spent pulping liquors are valued at a discount to the least cost alternative fossil fuel in the mill--natural gas or residual fuel oil.

The level of the discount will depend on the inconvenience of using wood and process wastes in comparison to the next best alternative. The inconvenience costs depend on labour and other costs incurred in handling the wastes, disposing of the ash, etc. This component of the discount will tend to escalate with non-fuel costs. In addition, there will be a "variability" discount to account for the varying moisture content and organic composition of the wastes, as well as for the relative uncertainty of hog fuel supplies. The size of the latter discount is likely to vary with the cost of the alternative fuels being displaced.

Again, there are no data available to determine the size of the discount. Consequently, a wide range of discount factors are analysed--20, 50, and 80 percent. The selection of the discount affects the index of total energy consumption and can introduce biases as illustrated below.

Assuming that only two fuels are used--hog fuel and other fuel--then the rate of change of the (continuous) Divisia quantity index can be written as follows:

$$\dot{E} = \frac{a P_1 e_1}{TE} \dot{e}_1 + \frac{P_2 e_2}{TE} \dot{e}_2 \quad (B.1)$$

where

$\dot{E}$ = rate of change of the index
 e_1 = hog fuel consumption in energy units (joules)
 e_2 = other fuel consumption in joules
 a = hog fuel discount factor (< 1)
 P_1 = price of fuel displaced by hog fuel
 P_2 = price of other fuel, and
 $TE = aP_1e_1 + P_2e_2$ = total expenditures on fuel.

The effect of assuming a larger discount factor for hog fuel can be determined by differentiating (B.1) with respect to a . After simplification the result becomes:

$$\frac{\partial \dot{E}}{\partial a} = \frac{P_1 e_1 P_2 e_2}{TE^2} (\dot{e}_1 - \dot{e}_2) \quad (B.2)$$

This equation indicates that if hog fuel consumption grows more quickly than consumption of other fuels ($\dot{e}_1 > \dot{e}_2$), then a smaller price discount for hog fuel (i.e., larger a) will cause the index of total energy consumption to grow more rapidly. Furthermore, if the size of the discount decreases (a increases) over time, the index of total energy consumption will grow more rapidly if hog fuel consumption grows more quickly than other energy consumption.

Footnotes

¹The prices used for purchased fuel in this study are documented in Appendix C.

²For the mill-specific data on input energy used here, self-generated electricity refers to the production of power at industry-owned hydroelectric facilities. Cogeneration of electricity is treated as a transformation of energy occurring within the mill, and is embodied in the fuels (fuel oil, hog fuel, etc.) which produce steam for ultimate conversion into electric power.



APPENDIX C
PURCHASED FUEL PRICES

Appendix C

PURCHASED FUEL PRICES

This appendix documents the historical fuel prices used for computing the Divisia quantity index of energy consumption. Data on fuel prices, or on total expenditure by fuel type, are not available at the individual mill level and, therefore, aggregate published sources have been used.

Statistics Canada Publication 57-208 (Consumption of Purchased Fuel and Electricity, or CPFE)¹ reports values and quantities of fuels by province and by 4-digit SIC classification code. Information on "Pulp and Paper Mills" has been obtained through 1983, the last year of available data. Data prior to 1975 (i.e., for 1972) are based on a higher SIC classification--"Paper and Allied Industries"--and do not include a disaggregation of fuel oil demand.² In order to generate 1984 values, the 1983 CPFE prices have been extrapolated using the growth rates in average industrial sector fuel prices from Energy, Mines and Resources Canada's Interfuel Substitution Demand (IFSD) Model.

Tables C.1a through C.1f present both the nominal (undeflated) IFSD fuel prices and the nominal industry-specific CPFE prices for the years 1972 and 1976 through 1984. All prices have been converted from a fuel volume basis to an input energy basis using aggregate heat values from the IFSD model.³ As indicated in the tables, there are some significant differences between the average industrial IFSD prices and the industry-level CPFE prices. Therefore, the 1984 extrapolated fuel prices should be viewed with a degree of caution.

Table C.2 contains the historical indexes for deflating these nominal fuel prices to real or constant dollar (1971) prices. The resulting real fuel prices are shown in Tables C.3a through C.3f.

TABLE C.1a
NOMINAL FUEL PRICES - ELECTRICITY^a
(\$/GJ of input energy)^b

Year	British Columbia				Quebec			
	IFSD ^c		CPFE ^d		IFSD		CPFE	
	Price	%G.R. ^e	Price	%G.R.	Price	%G.R.	Price	%G.R.
1972			1.3607				1.2653	
1976	2.7927		2.3877	75.5	3.3690		1.7796	40.6
1977	3.4983	25.3	2.9229	22.4	3.6810	9.3	2.0665	16.1
1978	3.7459	7.1	3.2165	10.0	3.5820	(2.7)	2.4812	20.1
1979	3.9325	5.0	3.4675	7.8	4.7100	31.5	2.8115	13.3
1980	4.3622	10.9	4.2682	23.1	5.8140	23.4	3.1255	11.2
1981	5.0688	16.2	5.2908	24.0	6.5460	12.9	3.6448	16.6
1982	6.0243	18.9	6.6536	25.8	7.3908	15.2	4.5523	24.9
1983	6.7450	12.0	7.6989	15.7	8.4778	14.7	4.9135	7.9
1984	7.2720	7.8	8.3004 ^f	7.8	8.4920	0.2	4.9217 ^f	0.2

SOURCE: Statistics Canada 57-208; and Energy, Mines and Resources Canada, IFSD database.

^aUndeclared dollars.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPrices for the industrial sector from the IFSD Model.

^dValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208.

^ePercentage growth rate in price from previous year.

^fNot available, and so extrapolated using growth rate of IFSD price.

TABLE C.1b

NOMINAL FUEL PRICES - NATURAL GAS^a
(\$/GJ of input energy)^b

Year	British Columbia				Ontario			
	IFSD ^c		CPFE ^d		IFSD		CPFE	
	Price	%G.R. ^e	Price	%G.R.	Price	%G.R.	Price	%G.R.
1972			0.4248				0.4672	
1976	0.9021		0.9021	112.4	1.3764		1.3547	190.0
1977	1.1896	31.9	1.1874	31.6	1.3500	(1.9)	1.5398	13.7
1978	1.3138	10.4	1.4543	22.5	1.9058	41.2	1.8124	17.7
1979	1.5177	15.5	1.5877	9.2	2.0646	8.3	1.9352	6.8
1980	1.6576	9.2	1.7074	7.5	2.3654	14.6	2.2501	16.3
1981	2.4695	49.0	2.3012	34.8	3.0318	28.2	2.8373	26.1
1982	3.4020	37.8	3.1373	36.3	3.7636	24.1	3.4949	23.3
1983	3.3959	(0.2)	3.2320	3.0	4.1775	11.0	3.7821	8.2
1984	3.0265	(10.9)	2.8804 ^f	(10.9)	4.1775	0.0	3.7821 ^f	0.0

SOURCE: Statistics Canada 57-208; and Energy, Mines and Resources Canada, IFSD database.

^aUninflated dollars.

^bAll prices converted to an input energy basis using heat values from ENR's IFSD Model.

^cPrices for the industrial sector from the IFSD Model.

^dValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208.

^ePercentage growth rate in price from previous year.

^fNot available, and so extrapolated using growth rate of IFSD price.

TABLE C.1c

NOMINAL FUEL PRICES - HEAVY FUEL OIL^a
 (\$/GJ of input energy)^b

Year	British Columbia				Quebec			
	IFSD ^c		CPFD ^d		IFSD ^c		CPFD ^d	
	Price	%G.R. ^e	Price	%G.R.	Price	%G.R.	Price	%G.R.
1972 ^f			0.5309				0.4481	
1976	1.2687		1.2454	134.6	1.2814		1.2465	178.2
1977	1.6022	26.3	1.5899	27.7	1.5506	21.0	1.5248	22.3
1978	1.7554	9.6	1.7247	8.5	1.8390	18.6	1.8475	21.2
1979	2.2038	25.5	2.1840	26.6	2.1648	17.7	2.1599	16.9
1980	2.3714	7.6	2.3309	6.7	2.6965	24.6	2.6113	20.9
1981	3.2135	35.5	3.1760	36.3	3.4372	27.5	3.2982	26.3
1982	3.4361	6.9	4.1231	29.8	3.8409	11.7	3.7992	15.2
1983	3.6824	7.2	4.5492	10.3	4.6083	20.0	4.5581	20.0
1984	4.111	11.6	5.07878	11.6	5.139	11.5	5.08308	11.5

SOURCE: Statistics Canada 57-208; and Energy, Mines and Resources Canada, IFSD database.

^aUninflated dollars. Used for Residual Fuel Oil.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model. Prices for the industrial sector from the IFSD Model.

^cValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208. Percentage growth rate in price from previous year.

^dAverage fuel oil price used for 1972.

^eNot available, and so extrapolated using growth rate of IFSD price.

TABLE C.1d

NOMINAL FUEL PRICES - LIGHT FUEL OIL^a
(\$/GJ of input energy)^b

Year	British Columbia			Quebec		
	IFSD ^c		CPFE ^d	IFSD		CPFE
	Price	%G.R. ^e		Price	%G.R.	
1972 ^f			0.5728			
1976	1.8066		1.5711	2.1376		0.4835
1977	2.6334	45.8	2.3532	2.4259	13.5	1.7487
1978	2.7298	3.7	2.7060	2.6652	9.9	2.0672
1979	2.9826	9.3	3.0671	3.0917	16.0	2.4383
1980	4.0535	35.9	4.0575	4.1810	35.2	3.8087
1981	6.1577	51.9	5.6824	5.5550	32.9	4.1794
1982	7.4593	21.1	7.3148	6.7932	22.3	6.7844
1983	8.2353	10.4	7.6096	7.4811	10.1	7.2800
1984	8.703	5.7	8.04188	8.013	7.1	7.79768
						7.1

SOURCE: Statistics Canada 57-208; and Energy, Mines and Resources Canada, IFSD database.

^aUndeclared dollars. Used as a proxy for Distillates.

^bPrices converted to an input energy basis using heat values from EHR's IFSD Model.

^cPrices for the industrial sector from the IFSD Model.

^dValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208.

^ePercentage growth rate in price from previous year.

^fAverage fuel oil price used for 1972.

^gNot available, and so extrapolated using growth rate of IFSD price.

TABLE C.1e

NOMINAL FUEL PRICES - LPCe^a
(\$/GJ of input energy)^b

Year	British Columbia				Quebec			
	IFSD ^c		CPPFD		IFSD		CPPFE	
	Price	%G.R. ^e	Price	%G.R.	Price	%G.R.	Price	%G.R.
1972			1.7284				2.4919	
1976	3.4275		3.8931	125.1	3.7017		4.0457	62.4
1977	3.6361	6.1	4.2506	9.2	4.0175	8.5	4.3330	7.1
1978	3.8451	5.7	4.4519	4.7	4.3876	9.2	4.7998	10.8
1979	4.2030	9.3	4.7666	7.1	4.6653	6.3	4.8727	1.5
1980	5.1042	21.4	5.7453	20.5	5.4624	17.1	5.4208	11.2
1981	6.5366	28.1	8.6272	5.2	6.9387	27.0	8.2450	52.1
1982	5.5581	(15.0)	8.8824	3.0	5.9000	(15.0)	8.0688	(2.1)
1983	7.5915	36.6	10.0747	13.4	8.0585	36.5	9.8456	22.0
1984	7.9347	4.5	10.5302f	4.5	8.4228	4.5	10.2907f	4.5

^aUndeclared dollars.

^bAll prices converted to an input energy basis using heat values from EHR's IFSD Model.

^cPrices for the industrial sector from the IFSD Model.

^dValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208.

^ePercentage growth rate in price from previous year.

^fNot available, and so extrapolated using growth rate of IFSD price.

TABLE C.1f

NOMINAL FUEL PRICES - COAL^a
(\$/GJ of input energy)^b

Year	Quebec			
	IFSDC		CPPed	
	Price	IG.R.e	Price	IG.R.
1972			0.6617	
1976	1.7447		1.2921	95.3
1977	1.6479	(5.5)	1.3667	5.8
1978	1.8338	11.3	1.4564	6.6
1979	1.7956	(2.1)	1.6034	10.1
1980	2.3352	30.1	1.8469	15.2
1981	3.1701	35.8	1.9524	5.7
1982	3.5898	13.2	2.0895	7.0
1983	3.3989	(5.3)	2.4310	16.3
1984	3.590	5.6	2.5677f	5.6

^aUndeinfated dollars. Used for Lignite Coal and Coke.

^bAll prices converted to an input energy basis using heat values from EHR's IFSO Model.

^cPrices for the industrial sector from the IFSO Model.

^dValues of fuels divided by fuel quantities for pulp and paper mills from Statistics Canada 57-208.

^ePercentage growth rate in price from previous year.

^fNot available, and so extrapolated using growth rate of IFSO price.

TABLE C.2
PRICE INDEXES
(1971 = 100.0)

Year	Canada		B.C.	Ontario	Quebec
	GDP ^a	ISPI ^b	GDP ^c	GDP ^c	GDP ^c
1972	97.7	100.5	97.9	99.5	98.8
1976	211.4	191.6	204.0	184.0	197.1
1977	217.2	204.6	211.0	192.6	202.6
1978	218.0	216.4	212.6	198.3	206.8
1979	283.4	258.2	269.4	238.7	259.6
1980	331.9	300.1	318.7	271.9	299.9
1981	346.5	329.5	333.4	288.6	316.5
1982	317.3	336.1	309.2	282.8	300.9
1983	301.7	317.5	298.7	285.8	294.4
1984	N.A. ^d	358.9	337.6 ^e	323.1 ^e	332.8 ^e

SOURCE: Statistics Canada 61-202, 61-213 and 62-011.

^aGross domestic product deflator for Pulp and Paper Mills.

^bIndustry selling price index for Paper and Allied Industries.

^cGross domestic product deflator for Paper and Allied Industries.

^dNot available.

^eNot available, and so extrapolated using growth rate in ISPI.

TABLE C.3a
REAL FUEL PRICES - ELECTRICITY^a
(\$/GJ of input energy)^b

Year	British Columbia		Quebec	
	Price	%G.R. ^c	Price	%G.R.
1972	1.3899		1.2807	
1976	1.1704	(15.8)	0.9029	(29.5)
1977	1.3853	18.4	1.0200	13.0
1978	1.5129	9.2	1.1998	17.6
1979	1.2871	(14.9)	1.0830	(9.7)
1980	1.3393	4.1	1.0422	(3.8)
1981	1.5869	18.5	1.1516	10.5
1982	2.1519	35.6	1.5129	31.4
1983	2.5775	19.8	1.6690	10.3
1984	2.4586 ^d	(10.3)	1.4767 ^d	(13.7)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dExtrapolated using growth rate in IFSD price from Table C.1.

TABLE C.3b
 REAL FUEL PRICES - NATURAL GAS^a
 (\$/GJ of input energy)^b

Year	British Columbia		Ontario	
	Price	%G.R. ^c	Price	%G.R.
1972	0.4339		0.4695	
1976	0.4422	1.9	0.7363	56.8
1977	0.5627	27.3	0.7995	8.6
1978	0.6841	21.6	0.9140	14.3
1979	0.5893	(13.9)	0.8107	(2.0)
1980	0.5357	(9.1)	0.8275	2.1
1981	0.6902	28.8	0.9831	18.8
1982	1.0147	47.0	1.2358	25.7
1983	1.0820	6.6	1.3233	7.1
1984	0.8532 ^d	(25.9)	1.1706 ^d	(11.5)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dExtrapolated using growth rate in IFSD price from Table C.1.

TABLE C.3c
 REAL FUEL PRICES - HEAVY FUEL OIL^a
 (\$/GJ of input energy)^b

Year	British Columbia		Quebec	
	Price	%G.R. ^c	Price	%G.R.
1972 ^d	0.5423		0.4535	
1976	0.6105	12.6	0.6324	39.4
1977	0.7535	23.4	0.7526	19.0
1978	0.8112	7.7	0.8934	18.7
1979	0.8107	(0.1)	0.8320	(6.9)
1980	0.7314	(9.8)	0.8707	4.7
1981	0.9526	30.2	1.0421	19.7
1982	1.3335	40.0	1.2626	21.2
1983	1.5230	14.2	1.5483	22.6
1984	1.5044 ^e	(7.1)	1.5251 ^e	(3.9)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2. Used for Residual Fuel Oil.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dAverage fuel oil price used for 1972.

^eExtrapolated using growth rate in IFSD price from Table C.1.

TABLE C.3d
 REAL FUEL PRICES - LIGHT FUEL OIL^a
 (\$/GJ of input energy)^b

Year	British Columbia		Quebec	
	Price	%G.R. ^c	Price	%G.R.
1972 ^d	0.5851		0.4894	
1976	0.7701	31.6	0.8872	81.3
1977	1.1153	44.8	1.0203	15.0
1978	1.2728	14.1	1.1791	15.6
1979	1.1385	(10.6)	1.0700	(9.3)
1980	1.2731	11.8	1.2700	18.7
1981	1.7044	33.9	1.3205	4.0
1982	2.3657	38.8	2.2547	70.7
1983	2.5487	7.7	2.4728	9.7
1984	2.3820 ^e	(12.1)	2.3397 ^e	(7.7)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2. Used for Distillates.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dAverage fuel oil price used for 1972.

^eExtrapolated using growth rate in IFSD price from Table C.1.

TABLE C.3e
 REAL FUEL PRICES - LPC^a
 (\$/GJ of input energy)^b

Year	British Columbia		Quebec	
	Price	%G.R. ^c	Price	%G.R.
1972	1.7667		2.5222	
1976	1.9084	8.0	2.0526	(18.6)
1977	2.0145	5.6	2.1387	4.2
1978	2.0940	3.9	2.3210	8.5
1979	1.7693	(15.5)	1.8770	(19.1)
1980	1.8027	1.9	1.8075	(3.7)
1981	2.5876	43.5	2.6051	44.1
1982	2.8727	11.0	2.6816	2.9
1983	3.3728	17.4	3.3443	24.7
1984	3.1191 ^d	(13.1)	3.0877 ^d	(9.9)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2.

^bAll prices converted to an input energy basis using heat values from EMR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dExtrapolated using growth rate in IFSD price from Table C.1.

TABLE C.3f
 REAL FUEL PRICES - COAL^a
 (\$/GJ of input energy)^b

Year	Quebec	
	Price	%G.R. ^c
1972	0.6697	
1976	0.6556	(2.1)
1977	0.6746	2.9
1978	0.7043	4.4
1979	0.6176	(12.3)
1980	0.6158	(0.3)
1981	0.6169	0.0
1982	0.6944	12.6
1983	0.8257	18.9
1984	0.7704 ^d	(9.0)

SOURCE: Tables C.1 and C.2.

^aConstant 1971 dollars. CPFE prices in Table C.1 deflated by regional price index in Table C.2. Used for Lignite Coal and Coke.

^bAll prices converted to an input energy basis using heat values from ENR's IFSD Model.

^cPercentage growth rate in price from previous year.

^dExtrapolated using growth rate in IFSD price from Table C.1.

Footnotes

¹Statistics Canada, Consumption of Purchased Fuel and Electricity by the Manufacturing, Mining, Logging and Electric Power Industries, Catalogue 57-208.

²Fuel oil demand includes heavy fuel oil, light fuel oil, kerosene and diesel oil.

³These heat values are constant across provinces and over time:

Electric Power	3.6 TJ per GW.h
Natural Gas	37.23 TJ per 10 ⁶ cubic metres
Residual Fuel Oil	41.73 TJ per 10 ³ cubic metres
Light Fuel Oil	38.68 TJ per 10 ³ cubic metres
LPGs	26.56 TJ per 10 ³ cubic metres
Coal	29.3 PJ per kilotonne

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NOTES